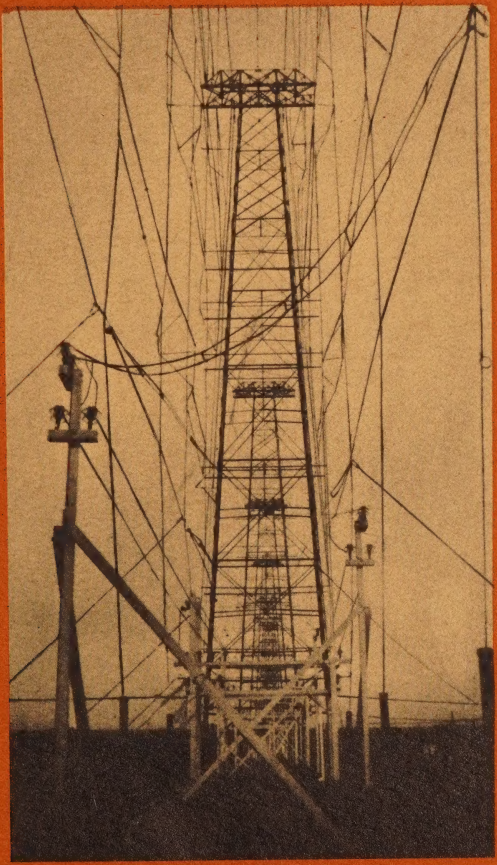
SHORT-WAVE TRANSATLANTIC RADIO-TELEPHONY



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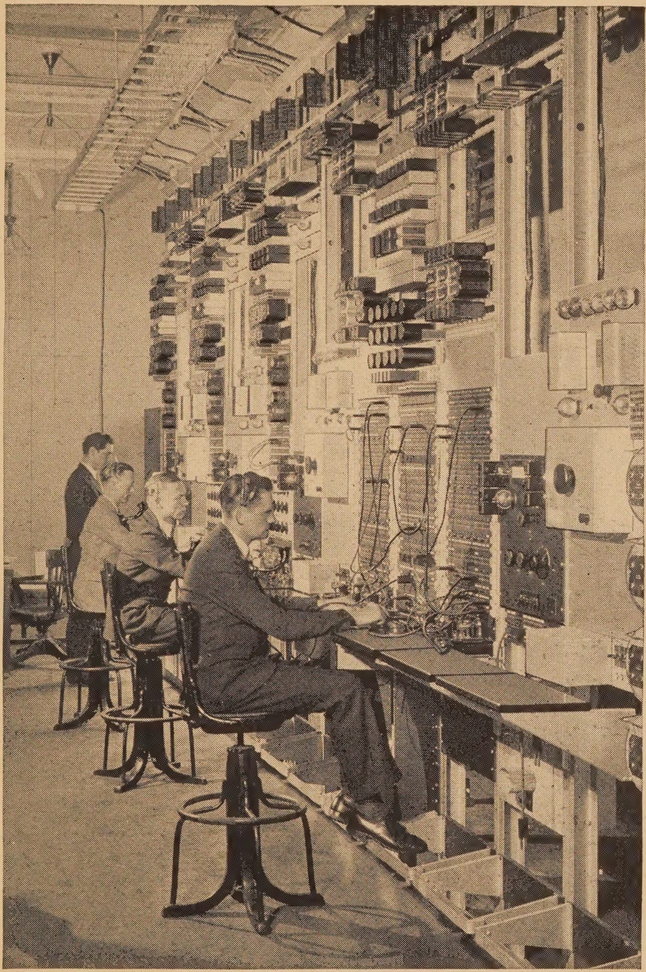

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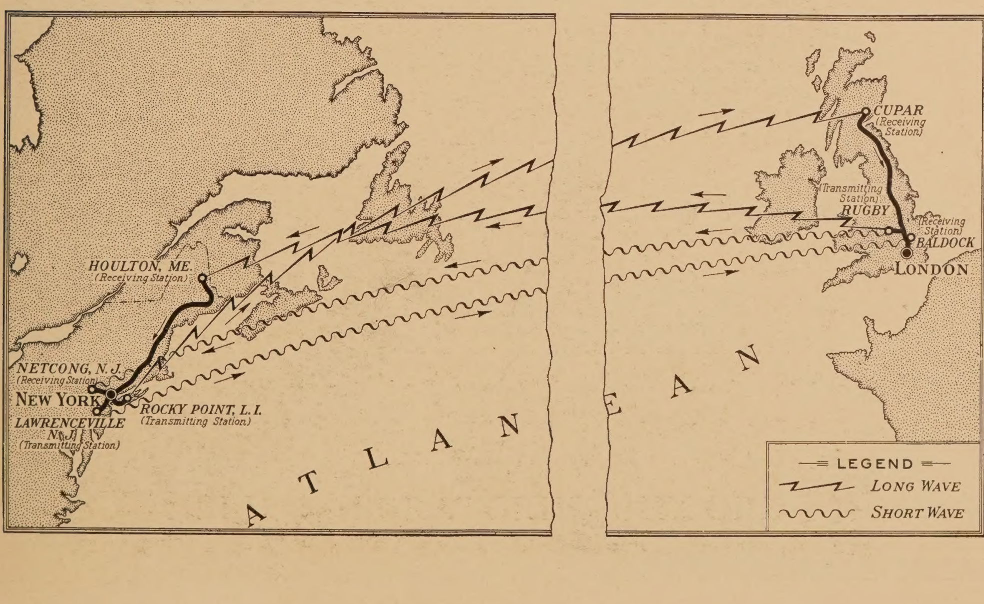
Fairchild Aerial Surveys, Inc.

A general view of the transmitting station at Lawrenceville, New Jersey

TWO-WAY transatlantic telephone service was inaugurated by the American Telephone and Telegraph Company on January 7, 1927, over long-wave radio links. For this system the American transmitter was located at Rocky Point, Long Island, and the receiver at Houlton, Maine. Its popularity was not only instant but enduring; and the great increase in transatlantic business made evident a coming necessity for more channels.

Such, however, was the growth in all uses of radio that there were few unassigned channels in the range of wavelengths generally used commercially. For new message-carrying facilities, therefore, attention turned to the short-wave range. This range, first cultivated by amateurs, had been under investigation for several years and the conclusion reached that it would afford commercial channels. A one-way short-wave channel was established early in 1927 as a supplement to the existing eastbound long-wave channel. Two-way transatlantic telephone service over short-wave paths was initiated by the American Telephone and Telegraph Company in 1928. And on June 1, 1929 it opened two new short-wave stations and a new communication system.

The development of this short-wave system was carried out in Bell Telephone Laboratories. The various phases of that development were described in *Bell Laboratories Record,* between July and October, 1929, by engineers who had been intimately connected with it. Their articles, which summarize almost every aspect of the American stations, are here reprinted together to form an inclusive record of the achievement.



The American Radio Stations

By W. WILSON
Assistant Director of Research

NEW short-wave stations for transoceanic communication have been opened at Lawrenceville, New Jersey, for transmitting and at Netcong, New Jersey, for receiving.

Four channels will be put into operation. One of these will replace the present experimental channel, through which messages have been transmitted from our Deal Beach station and received at Netcong for the last two years.

Two of the others will be added to the European service during the coming months, and the fourth will establish telephone communication with South America.

The Lawrenceville property is approximately 800 acres in extent and has two buildings. The main building houses the general offices and line terminal equipment in addition to two of the radio transmitters. The second building is similar to the first except that provision is merely made for the radio equipment.

Each transmitter is designed for operation on those frequencies in the short-wave range which are found to be necessary for communication during the hours of operation. These frequencies are approximately 19,000, 14,000, and 9,000 kilocycles, corresponding to 16, 22, and 33 meters wavelength.

Antenna towers and main building at Lawrenceville

Buildings at Netcong

Carrier power at these frequencies is obtained by amplification of the suitable harmonics from crystal oscillators with fundamental frequencies in the neighborhood of 3,000 kilocycles. Considerable care is taken with regard to constancy of temperature and other operating conditions to ensure the stability of these oscillators.

By the usual method of plate modulation, the voice signals are applied to the carrier, and the modulated power is in turn amplified by two stages employing water-cooled tubes. The output from the sets is fed by transmission lines to appropriate antennas, located in some cases several hundred feet away.

Power for the transmitter is purchased from central-station lines. After transformation to appropriate voltages, that required for plate circuits is rectified and filtered. For the two final stages power is delivered at 10,000 volts from a rectifier employing six water-cooled tubes. Elaborate precautions are taken to insure safety in operation by an interlocking system which prevents the opening of any enclosure before the power has been shut off. In addition the doors of the apparatus are equipped with safety switches which throw the main circuit breaker when the doors are opened if there should be any failure of the interlocking system.

One of the advantages of a short-wave system is its adaptability to the use of antennas which concentrate the transmitted energy into a beam in the direction required. This greatly enhances the signal at the receiver.

In general, directive antennas are suitable for only one wavelength. Since each transmitter must be able to work on any of three wavelengths, nine antennas are required. These consist of curtains of vertical and horizontal wires strung between towers 180 feet high and 250 feet apart. Each antenna is 500 feet wide and the nine antennas are lined up end to end giving a total length of 4500 feet. The gain to be expected from the use of these antennas over a single vertical wire is from fifteen to twenty decibels.

The Netcong receiving station com-

Engineers in charge of the development of the short-wave radio transmitters and receivers. Left to right: A. A. Oswald, M. J. Kelly, W. Wilson, R. A. Heising, J. C. Schelleng, H. T. Friis

prises about 400 acres. As in the case of the transmitting station three wavelengths are needed for each of four receiving sets, necessitating the use of 12 antennas. Each receiving set is housed in a separate building and the general offices and power plant are in still another building.

The receiving sets have two stages of radio-frequency amplification, six stages of intermediate amplification and one stage of audio amplification. An automatic volume control minimizes fading effects. Actual volume at which the energy is put on the telephone line is adjusted by means of repeaters in the line terminal equipment.

The antennas used at the receiving end are also directive. Their directivity not only makes them more efficient from the standpoint of picking up signals from a preferred direction but it also by its discrimination against signals coming from other directions materially reduces interference both from static and from other stations. The antennas are six wavelengths long and are connected to their respective sets by transmission lines.

In selecting a site for the receiving station great care was taken to avoid the proximity of well-travelled automobile and airplane routes, because of the interference with signals created by unshielded ignition systems. With the adoption of radio communication for airplanes their ignition systems must perforce be shielded but no relief can be expected from interference from the present type of automobile engine. Limits have been prescribed beyond which automobiles are not permitted unless their ignition systems are adequately shielded. Horses are used for much of the transportation immediately around the station.

Transmitting Station at Lawrenceville

By M. E. FULTZ
Radio Research

AT the request of the American Telephone and Telegraph Company, the problem of planning a four-channel short-wave radio transmitting station, for commercial telephone service to Europe and South America, was undertaken in the spring of 1928. The selection of transmitting frequencies, circuits and antennas to be used, was based upon experience with the installation at Deal and the development work conducted at that station during the previous two years.

Due to the particular type of antenna selected, and the fact that each transmitter was to operate on any one of three assigned frequencies, a total of twelve independent antennas for the four channels was necessary, each requiring a linear distance of 500 feet for its structure. These antennas have directional characteristics which necessitate placing them broadside to the direction in which transmission is desired. Since it was not considered advisable to place obstructions directly in front of any antenna, straight line formations were selected. With this arrangement, an extremely long line of towers results when several channels transmit in the same direction. This is the case at Lawrencevile, N. J., where three of the four transmitters work to England.

The space requirements for a single antenna were arrived at on the basis of a fixed linear distance between towers which would most satisfactorily accommodate any one of the three antennas. This was done so that all tower spacings would be uniform and flexibility obtained for shifting groups or interchanging the antennas in a group in case it was later found desirable to make such changes.

In order to avoid undue loss in the transmission lines feeding these antennas, each transmitter should be located as nearly central to its three antennas as possible. It was, therefore, decided to separate the four transmitters and install not more than two in a single building. Accordingly two two-story buildings identical in layout, insofar as the transmitter installations are concerned, were erected by the American Telephone and Telegraph Company.

On the ground floor of each building, occupying the entire width at the rear, are transformer vaults and rooms for water-cooling units. Directly in front of these and also extending the full width of the building is the power room, a general view of which is shown in Figure 1. There are three motor-generator sets to a group for supplying power to the various units of one transmitter, and three such groups located in this room. The left and right hand groups are the regular machines for the two transmitters, while those of the middle group serve as spares for either Between each group of machines, in a

screened enclosure, is located a transfer switch unit. It consists of three groups of double-throw gang-operated switches, which, when thrown in the proper direction, substitute entire spare motor-generator sets, including their automatic starting compensators, for the corresponding regular units associated with a transmitter. An interlocking system prevents the simultaneous use of a spare motor-generator set on two channels.

On the right hand side of the room is a standard twenty-four-volt power plant to meet the requirements of the telephone line-terminal equipment. On the left, between the first two automatic starting compensators, one of the generator noise filters is visible. This particular filter, the coil of which has a current-carrying capacity of six hundred amperes, is used in the supply line to the filaments of the transmitter tubes. Water pumps, water storage tanks, and a motor-generator set for sleet-melting, are also located in the power room.

As a precaution against vibration in the building, all rotating machinery was mounted on concrete piers which rest on cork mats several feet below the power room floor. Cork linings surround these piers where they pass through the floor.

Directly over the power room and of equal floor area is the transmitter room (Figure 2). Here are located two transmitters, in line, on one side of the room and two power-control boards, in line, on the other. A transmitter and its power-control board face each other with a seven foot aisle between them. Associated with each transmitter is an audio-frequency control turret, located on a desk which stands in this aisle near the center of the room. The radio operator, in this position, can communicate directly

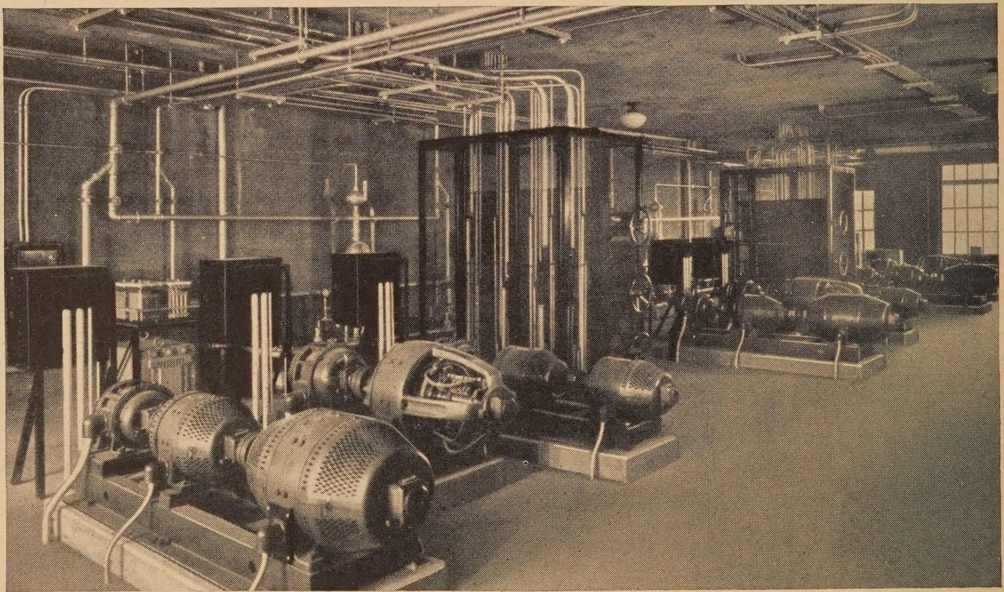


Fig. 1—General view of power room, showing the three groups of motor-generators (the center one a spare) for supplying the power to the transmitters, and the two screened transfer switch units

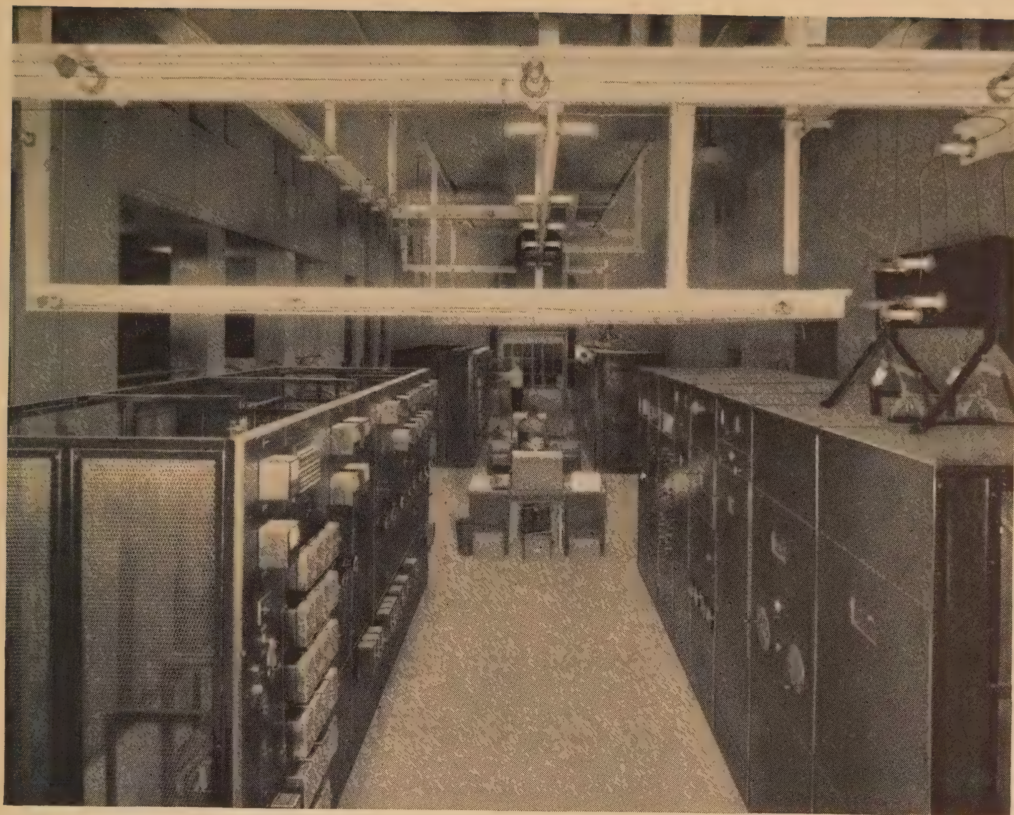


Fig. 2—General view of transmitting room. Left, power boards; right, transmitters; center, monitoring desks; left center room, rectifiers

with the New York control operator and monitor the input and output of the radio transmitter.

Extending back over the top of the middle transformer vault from the center of the room, and at a slightly higher floor level, is a room containing two six-phase high-voltage rectifiers (Figure 3), for supplying direct current to their respective transmitters. Beneath the rectifiers, on each side of the middle transformer vault, is a high-voltage switch chamber. Each contains a double-throw 25,000-volt switch by means of which either rectifier can be transferred from its regular transformer to a common spare. The transfer not only involves substituting a transformer but also all other equipment located in a transformer vault. In addition, therefore, to the eight high-voltage connections, provision is made for changing control circuits and the connections to certain protective features by mechanically connecting a twelve-pole double-throw switch to the high-voltage switch. With this arrangement a complete substitution of transformer-vault equipment is possible by operating a single switch handle in the transmitter room (Figure 4).

The equipment comprising each transmitter proper is contained in seven independently shielded units mounted side by side on a common sub-base. Three of the units are devoted to input equipment and the

other four to power amplifiers and their associated circuits.

The power-control board (Figure 5) consists of motor-generator control-panels and distribution panels, nine in all, equipped with the necessary apparatus for controlling and applying power to the associated transmitter. All apparatus is remotely controlled from this point. Independent control of the various motor-generator sets may be had from their respective panels and power applied to the transmitter by working in the proper sequence. The final step is the application of high voltage to the plates of the power-amplifier tubes, which is possible only when conditions are such that it will cause no damage. The fulfillment of these conditions is insured through the agency of an alarm and protective circuit, which is also effective in turning off the high voltage should trouble develop while the transmitter is in operation. It consists of a group of relays with associated signal lamps and may justly be termed the guardian of the transmitter. Most of these relays are located on the second panel from the left and are clearly visible in Figure 5. The signal lamps, of which there are forty-eight, are located within the rectangular area at the top of the panel. Thirty-six of these lamps serve to indicate circuit conditions prior to applying high voltage to the transmitter and causes of interruptions thereafter. These indications are specific to the more probable difficulties, and group the remaining in such a manner that their causes may readily be determined.

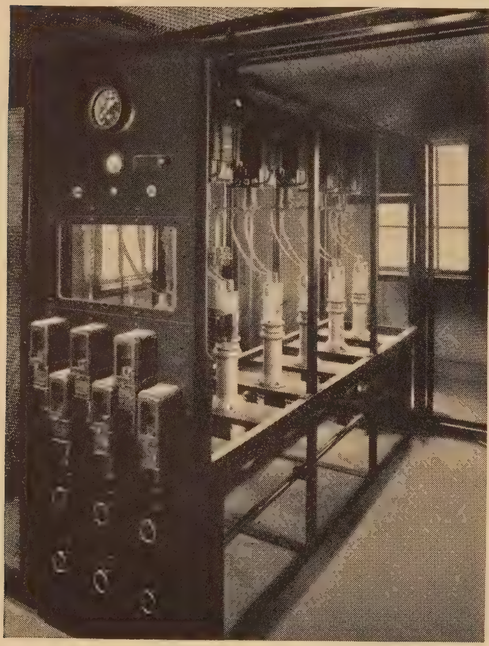


Fig. 3—One of the two six-phase high-voltage rectifiers for supplying direct current to the transmitters, located in a raised room leading off the center of the transmitting room

A guardian is not always infallible; sometimes it becomes necessary to guard the guardian. To this end the power supply for the alarm and protective circuit has been subdivided into twelve independently fused circuits. Twelve signal lamps connected to the load side of the fuses indicate fuse and power-supply conditions on these circuits. The lamps have a two-fold purpose: they indicate whether the alarm and protective circuit is telling the truth; and if it is not, they reduce to one-twelfth the places where this circuit is to be investigated for trouble.

When trouble develops in the transmitter itself, the protective circuit disconnects the high-voltage plate supply to the power amplifiers. Some of the conditions which cause this circuit to function are: overloads in amplifier and rectifier anode circuits; excessive water temperature; and failure of grid-biasing potential, filament-heat-

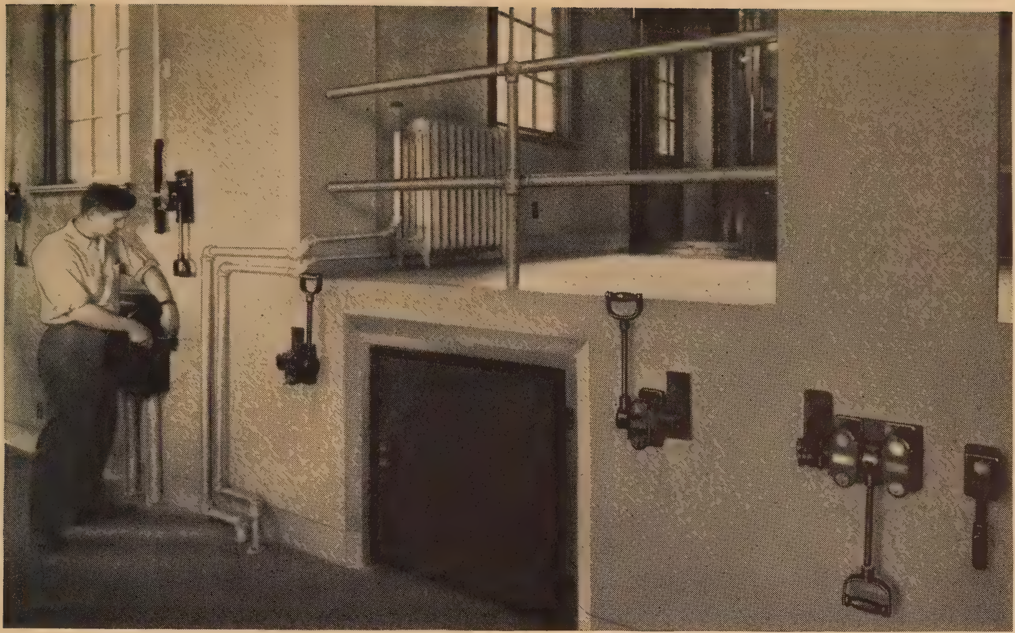


Fig. 4—Switch-handles of the interlocking system, in the transmitting room

ing supply or water flow. Each time an interruption occurs, one or more lamps go out and an audible signal operates for ten seconds to attract the station-operator's attention. By consulting the signal-lamp panel, causes for interruptions, and in most cases the particular thing responsible, may readily be ascertained and the transmitter returned to service with a minimum loss of time. An effective system should always indicate danger when something happens, regardless of whether it is a bonafide failure in equipment or a defect in the signal itself. In the system used at Lawrenceville, signal lamps operate on the principle of "light on" when conditions are correct and "light off" when trouble occurs. Had the reverse scheme been selected, a burned-out lamp might cause endless delay. A dark lamp in the present system, when the circuit is operating normally, convicts itself.

The power-control board has also been equipped with a master control system, to facilitate operations during routine handling of the set in commercial service. By throwing one switch the master control may be cut into or out of service. If it is in service, all equipment is automatically started and power applied to the transmitter by momentarily depressing the master "start" button. This completes all necessary operations up to the final step of applying the high voltage to the power amplifiers. The transmitter may be shut down by depressing the master "stop" button.

Each channel is provided with its own water-circulating system for cooling the anodes of the rectifier and power-amplifier tubes. It is, while operating, a closed circulating system, consisting of two water pumps, a water meter, three water-cooling units (Figure 6), a storage tank, and the necessary valves and the like. A closed circulating system is one in which the column of water is unbroken from

the discharge side of the pump to the suction side. At Lawrenceville this is the condition which exists when the pump is operating; but, as soon as the pump stops, all water drains from the cooling units, and the pipes to and from them, into the storage tank in the power room.

In designing a water-cooling system for vacuum tubes it is important to prevent aeration of water and to eliminate air circulating in the water columns around tube anodes. Precaution against trouble from the latter was taken by the installation of air valves at strategic points in the feed and discharge lines. For the proper operation of the cooling units it is necessary to locate them in a room open to the outside atmosphere and for this reason draining is essential to prevent freezing of the water in winter during idle periods. Although the discharge side of the system drains when the pump stops, water is retained in the tube jackets at all times by check valves in the feed line. Only one of the two pumps is used to circulate water. Either can be cut into service, and a change from one to the other can be effected, from the power control board. It is unnecessary to operate valves, and the attendant, therefore, is not required to leave the transmitter room in order to make a change.

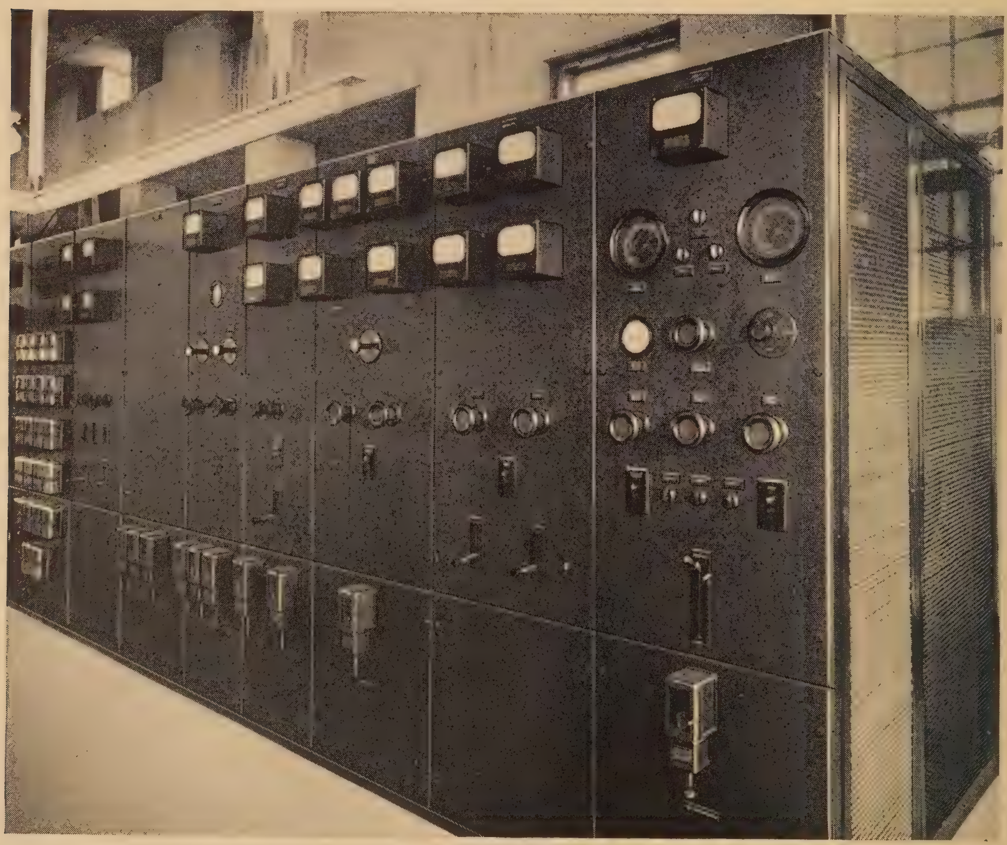


Fig. 5—One of the two power-control boards, in the transmitting room, for remotely controlling the power supply to the transmitters

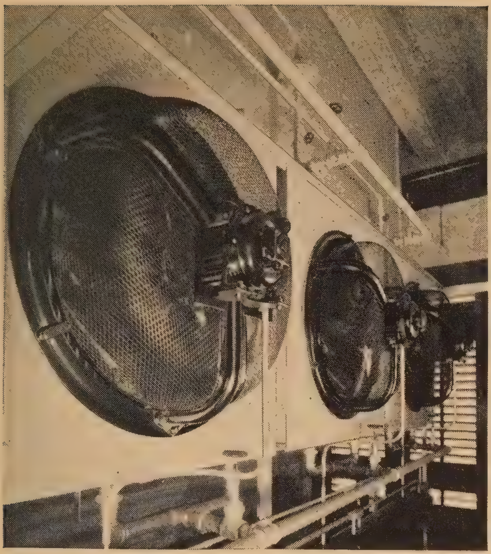


Fig. 6—The three water-cooling units associated with water-cooled vacuum tubes in transmitters and rectifiers

At present one and eventually two three-phase power-transmission lines, following different routes from the Lawrenceville substation of the Public Service Electric and Gas Company, will supply power to the radio station. At the property edge the overhead line terminates and underground cable-runs continue to outdoor substations. Each building has its own substation, where the voltage is stepped down from 4000 to 2300 volts, and whence four 2300-volt cables supply all power for the building.

Two of these cables, each of which supplies one transmitter, terminate in the power-transformer vaults of their respective transmitters. A bank of step-down transformers in each vault supplies all auxiliary power requirements for one transmitter at 220 volts. The main load, the rectifier transformer, connects directly to the 2300-volt supply and steps up the voltage to 12,600 maximum. A tie cable between the two power-transformer vaults permits the operation of two transmitters on a single cable in case of a failure on one cable.

The other two 2300-volt cables, one of which is a spare, provide for the building's light and power requirements. They terminate in a vault in another section of the building which is altogether independent of the transmitter layouts.

For the safety of personnel and the protection of equipment in the

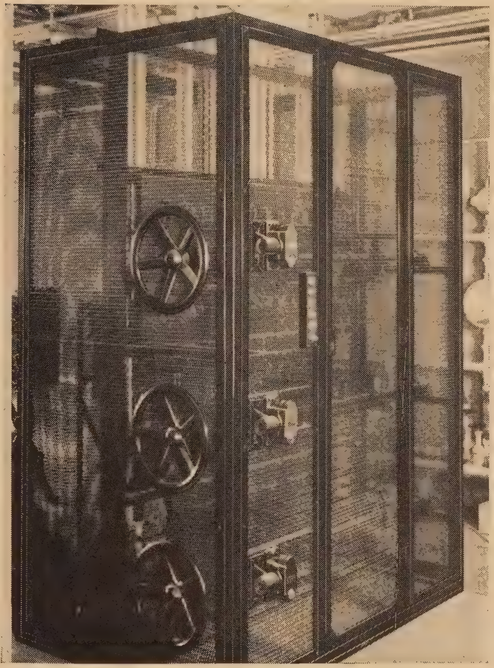


Fig. 7—One of the two transfer switch units, in the power room, for substituting motor-generator sets

plant an interlocking system has been adopted which is similar to that employed in modern central power stations but modified to meet the special requirements of the radio installation. It is a mechanical, key-operated scheme, in which the locking units are attached directly to switch-operating handles or vault-enclosure doors. Its protective feature lies in the fact that

a particular key is required to perform a certain operation. The completion of the operation locks the key in the unit and releases another key which permits executing a subsequent operation. In some cases where several conditions must be satisfied before it is safe to replace a key, a unit known as a transfer-key interlock is used, in which several keys are required, each in its proper place, to free a single key.

Some operations which the interlocking system prevents are: opening disconnect switches under load; gaining admittance to "live" enclosures; throwing switches in the wrong sequence; and tying two transmitters to a single spare piece of equipment. The layout is arranged for operating convenience, and in such a manner that its use will not occasion undue loss of time. To this end, for example, the disconnect-switches in the transformer vaults are remotely controlled by operating handles located in the transmitter room (Figure 4).

A near view of one of the transfer-switch units appears in Figure 7. Here the interlock units controlling the movement of the switches, a key box, and an enclosure-gate lock, are clearly visible. The key permitting entrance to this unit occupies the lower position of the key box. It is shown in place and not available until five conditions have been satisfied, and five keys obtained and inserted in their proper places in this unit. Upon removing the lower key the other five are locked in place and not obtainable until the removed key has been returned. The key operating any enclosure gate is not recoverable until the gate has been closed and locked.

This safety interlocking scheme is not confined to equipment within the building. It is a progressive system extending from the main 4000-volt power supply disconnect-switches, through the substations and buildings, to and including the antenna disconnect-switches.

The transmitters proper are not equipped with interlocking units such as have been described. Protection is obtained by an electrical system employing electric door-locks and door-switches, entirely automatic in its operation. Except by force or other unusual methods, access to any compartment is not possible until the high-voltage supply line to the transmitter has been grounded. In performing this operation, all sources of power supply to the transmitter, except that for heating filaments, are disconnected, and then all door-locks are energized. Upon opening any door, the grounding switch is locked in the grounded position and is not released until all transmitter doors have been closed again.

Adequate provision has been made for the expansion of this multi-channel transatlantic project. The present property will accommodate several more two-channel buildings of the present type, and their necessary antenna structures. Should future development make possible the use of longer transmission lines or smaller antennas, the layout of the building itself is such that additional transmitters may be installed by building to either side of the present structure.

The Radio Transmitters

By E. B. FERRELL
Radio Research

THE scheme of transmission used in transatlantic short-wave telephony, and the method by which this scheme is carried out, are fundamentally neither novel nor unfamiliar. Carrier power is obtained by amplifying the output from a crystal oscillator and multiplying its frequency, in two steps. The carrier is then modulated by the voice currents, and the resulting radio-frequency signals are amplified in two stages, and finally brought to the antenna where the carrier and both side bands are radiated. But with these fundamentals familiarity ends. The high powers and high frequencies employed have made necessary the design of new equipment and the solution of novel difficulties; a simple example well illustrates the nature of some of these problems.

Everyone believes that Ohm's law holds as well at twenty million cycles per second as it does at twenty cycles per second, but of the validity of this belief it is rather difficult to give any practical demonstration. An ordinary ammeter of the thermocouple type is no longer accurate at these frequencies. But worse than that inaccuracy is the difficulty of placing the meter in the circuit. If it is desired to measure the current in a tuned circuit, the conductor is cut, the meter is inserted and the reading is noted. Probably an appreciable part of the current in question is flowing through some stray capacity and not through the meter. This probability not only casts doubt on the accuracy of the measurement, but raises the question of what current really should have been measured. Almost certainly the insertion of the meter has changed the stray capacities, and the circuit must be retuned. The circuit may not even function as it did before.

Such stray, or distributed, capacities and inductances furnish the problems which, probably more than any other, distinguish the design of short-wave from that of other radio apparatus. This problem becomes more difficult with increase of either power or frequency. Increase in power requires higher voltages and currents, and thus larger apparatus spaced farther apart. The augmented bulk increases both the stray capacities and the unwanted inductance of leads, and higher frequency makes worse their bad effects. From this standpoint, higher frequency and higher power are mutually antagonistic.

The short-wave transmitter now used at Lawrenceville, N. J., on the transatlantic telephone circuit has a power limit of fifteen kilowatts. With the present method of modulation, which is the same as that used by broadcasting stations, this corresponds to sixty kilowatts on the peaks, with one-hundred per cent modulation. That is, a fifteen-kilowatt telephone set of this type could, with proper

Fig. 1—Broadside view of the Lawrenceville transmitter. Left to right: two units for speech-amplification, a unit for radio-frequency generation and modulation, a unit for each of the first stage of radio-amplification, the interstage circuit, and the last stage of amplification, and a double-sized unit for the output circuit. The overall length of the set is as much as three-eighths of a wavelength

power supply, be pushed to sixty kilowatts as a telegraph set.

The idea has been kept in mind that other systems, such as single sideband with suppressed carrier, might be used. For this reason the amplifiers, which could be used with any probable system of modulation, have been extensively developed instead of high-powered oscillators or harmonic generators. The amplifiers have also been made "linear,"* and have been built as a more or less distinct unit, so that they could be used with other types of input equipment employing new systems of modulation. Electrically "last," the amplifiers and their problems will be described first and most extensively.

Across the plates of the amplifier tubes there exist capacities, which are composed of the capacities within the tube, the direct capacity between the tube mountings, and the like. The value of this composite capacity in the first stage is about fifty micromicrofarads. In the last stage, where six tubes are used, it is about one hundred micromicrofarads. This value cannot be appreciably reduced by any change in design which now seems desirable. The reactance of one hundred micromicrofarads at twenty megacycles is about eighty ohms. Thus the designer is faced at the outset with a generator—the tubes—which has an internal impedance of a few thousand ohms, but across whose terminals is strapped an eighty-ohm reactance. This condition is an important limitation in the design of succeeding circuits.

Each short-wave channel operated by the Bell System for transoceanic telephony uses at least three frequencies, covering a range of at least two to one. To cover this range with a single variable condenser would be almost impossible. The initial capacity of the circuit is very high, and placing a variable condenser in parallel with it would only aggravate the condition of low reactance between plates. Moreover, at the voltages

* *The term "linear" is used here not to indicate that the tubes are operated on a linear portion of a dynamic characteristic, but that the output of the amplifier is proportional to the input.*

used, a condenser of any considerable capacity occupies many cubic inches. Instead of changing the operating frequency by a variable condenser, therefore, the coils of each circuit to be tuned to the final operating frequency must be changed for each such major change in frequency.

In the first stage of amplification, the variable element which makes exact tuning possible is a series condenser, inserted in the middle of the inductance. This lowers the net capacity in the circuit, thus permitting the use of larger and more easily constructed coils, and provides a means of coupling to the load of that stage. In the last stage, this series capacity becomes solely a coupling capacity, and the actual tuning is done by means of a short-circuited turn. Because of space and insulation difficulties a turn whose plane could be rotated was not used. Instead, its coupling to the main coils is varied by sliding it up or down, into or out of the field.

Problems of strays arise with inductances as well as with capacities. It is important that various parts of the transmitter be shielded from each other to prevent stray capacities from forming low-impedance feed-back couplings. To this end each stage of amplification, and at high power each tuned circuit, is in a separate shielded compartment. The elements themselves are rather large, and to keep down stray capacities, as well as to prevent actual voltage breakdown, they are spaced well away from the shields. This makes the compartments from twenty-four to thirty inches across. In an early design, the lead joining the interstage tuning condenser to the grid of the last stage was a little over two feet long. With the return circuit, this formed a loop of one or two microhenries inductance, causing serious resonance troubles within the operating range of frequencies. Since this inductance could not be reduced, it was increased a little to form a new mesh in the circuit. The interstage circuit is now a double-mesh circuit, with the variable tuning condenser as the common element.

Singing, the common name for spurious or parasitic oscillations, which caused a considerable amount of trouble in early development, is avoided at the operating frequency by neutralization. At higher frequencies this simple remedy is inefficient, and a very stubborn singing in the neighborhood of seven meters occurs. This has been eliminated principally by introducing resistance components into some of the stray capacities which are coupled to the circuit.

In addition to these two types of singing, there are five other well defined types. They have occurred for the most part in circuits involving choke coils and have been eliminated by the introduction of resistance in such a way as to have a damping effect at the singing but not at the operating frequency.

Although these problems of the amplifiers are aggravated due to the combination of high frequency and high power there, problems of as great difficulty beset the design of the low-powered equipment. An interesting example is that of providing crystal control for the high-frequency carrier.

Since crystals cannot be operated if they are as thin as would be required to give the frequencies used here, thicker crystals of lower frequency are used in conjunction with harmonic generators. The crystal is

of suitable thickness to give three and a third megacycles. The crystal oscillator drives a tube whose plate circuit is tuned to the third harmonic, ten megacycles. The action may be compared to that of driving a pendulum by giving it a sharp blow on every third swing. To gain much amplitude these blows must actually push the pendulum for very short intervals and must be very carefully timed. Electrically, the harmonic generator tube is operated with high grid bias so that current may flow in its plate for only a short part of each cycle of the driving frequency. The plate circuit is tuned in such a way that these short pulses of current flow only for a short part of every third cycle of the output frequency.

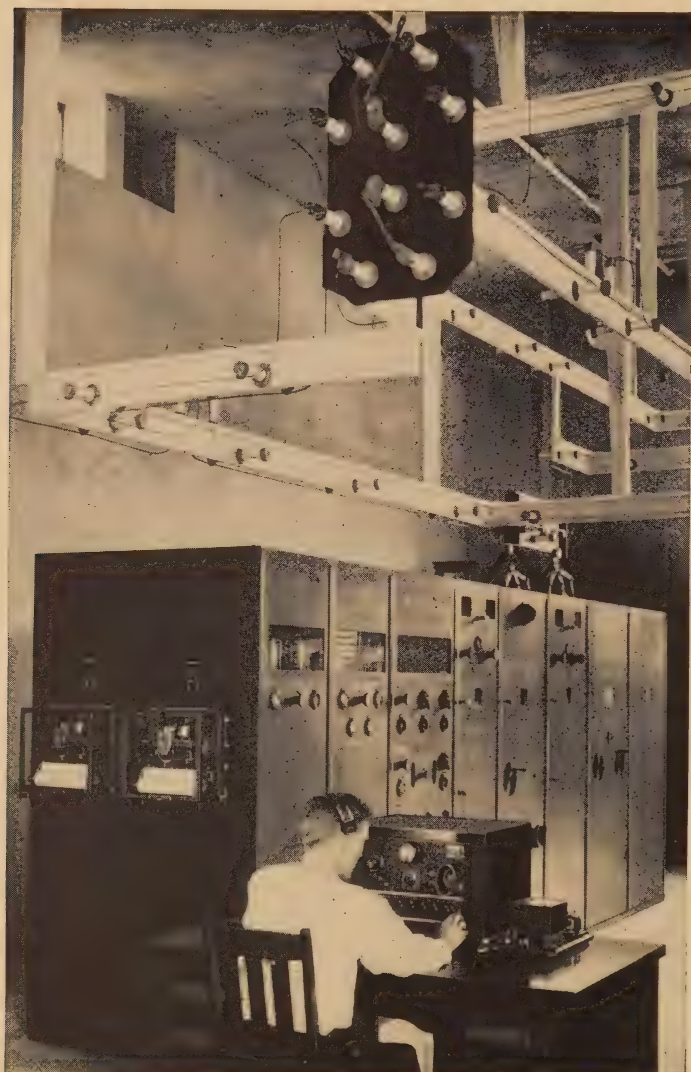


Fig. 2—The transmitter of Figure 1 in the transmitting room of Building A at Lawrenceville

This harmonic generator drives another which doubles the frequency, thus giving a final frequency of twenty megacycles. The plate circuit of this last harmonic generator is also the tuned circuit of a simple push-pull oscillator. Thus, although the oscillator supplies most of the power to this circuit, its frequency is controlled by the harmonic generator and indirectly by the crystal oscillator. The accuracy and stability of the final frequency is then the same as that of the crystal oscillator.

This controlled oscillator is modulated by means of a two-stage speech amplifier. The first stage has a six-hundred-ohm input impedance and uses a fifty-watt tube. The second stage uses four 250-watt tubes in parallel.

The need for simplicity and symmetry

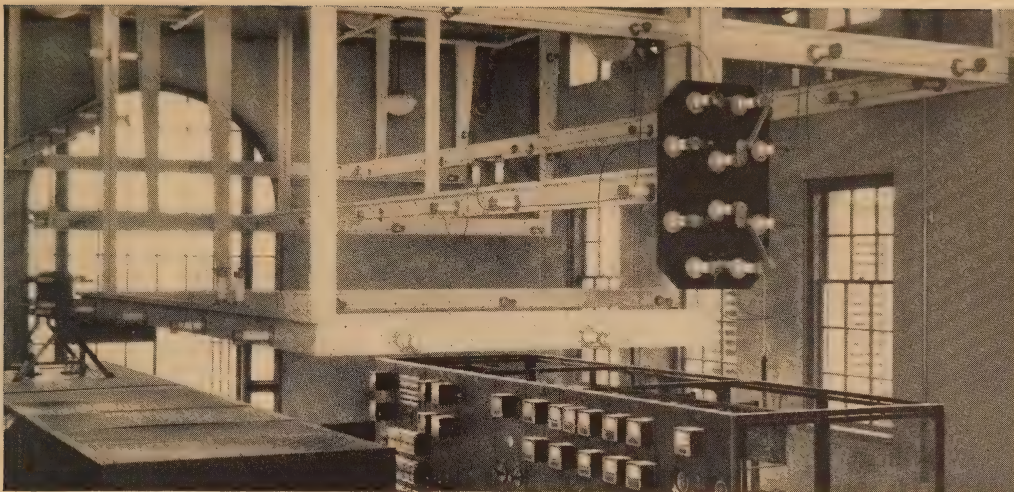


Fig. 3—A corner of the transmitter room

in the radio-frequency circuits has prevented the insertion of ammeters at convenient points, to study the characteristics of the transmitter. For the desired radio-frequency indications, therefore, monitoring rectifiers are used: five-watt tubes, used as two-element rectifiers, with 100,000 ohms resistance in their plate circuits. The high resistance, together with the stray capacities, constitutes a peak voltmeter which has linear characteristics. These radio-frequency voltmeters are used in pairs. The sum of the rectified currents of a pair is most often the reading of interest, but the difference of the two can be used to measure the unbalance of the circuits. A pair is coupled, through small capacities, to the grids of the first stage of high-power amplification, another to the grids of the last stage, and a third to the plates of the last stage.

The monitoring rectifier on the plates of the last stage of amplification is also used to judge the quality of the speech. Since it has linear characteristics, it serves for distortion measurements at audio frequencies. For example, if a pure eight-hundred-cycle tone is impressed on the transmitter, it, together with any of its harmonics which are produced by distortion in the transmitter, will be heard in the output of the monitor. Its amplitude can be measured by a standard audio-frequency measuring set. The ratio of that amplitude, expressed as peak current, to the direct current output of the monitor gives the per cent modulation. The harmonics may be separated by filters and measured, to indicate the amount of distortion. It is found that, when the transmitter is in proper adjustment and the audio-frequency tone is such as to give one-hundred per cent modulation, the distortion products are all as much as twenty-five decibels below the fundamental.

The frequency, twenty megacycles, corresponding to a wavelength of fifteen meters, is mentioned several times in this article, merely as a typical frequency. The sets installed at Lawrenceville will operate within the range of fourteen to forty-five meters with fifteen-kilowatt carrier output.

Transmitting Antennas

By E. J. STERBA
Radio Research

THE antenna system is the first object to attract the attention of a visitor to the plant at Lawrenceville, N. J., for the tower line west of Princeton is visible several miles from the station. Upon arriving at the station grounds, the antenna system appears to be a complicated network of wires on rugged towers extending more than a thousand feet past the observer. Appreciating that this extended construction is associated with directive transmission, he may feel that the structure is far too complicated for ready explanation. Yet the fundamentals of directive transmission and thus of the antenna are quite simple.

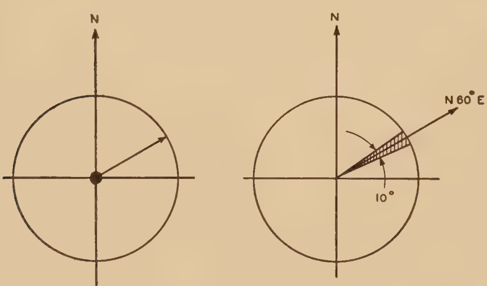


Fig. 1-*A* (*left*)—*Electric intensity about a broadcast transmitter. The area of the circle is proportional to the power radiated; Fig.* 1-*B* (*right*)—*Shaded area represents energy radiated if transmission is confined to a ten-degree sector*

A background of broadcast experience has familiarized nearly everyone with a transmitting antenna. The broadcast antenna is constructed so as to radiate in all directions with equal intensity, because broadcast reception is generally desired in all directions about the station. For this purpose a single vertical wire or several closely spaced vertical wires may be employed. If a vertical-wire antenna is erected upon an ideal transmitting site, the electric intensity in any direction about the antenna and for a constant distance from the antenna may be represented by the radii of a circle (Figure 1-A), signifying equally good reception in all directions about the antenna. The area of the circle is approximately proportional to the power radiated.

If, however, radio transmission is required only between two points, the radiation of energy in all directions other than that in which the receiving station lies is wasted effort. Suppose, for example, that the receiving station is located at N60°E with respect to the transmitter. If some modification is made in the antenna so that radiation occurs only between the radii five degrees to either side of the direction to the receiving station, and if the power of the radio transmitter is readjusted so that the signal-strength from the simple antenna and from the modified antenna are equal at the receiving station, the area of the shaded ten-degree sector in Figure 1-B is proportional to the power radiated—10/360 of that required

for the simple antenna. If this ideal case could be set up, the radio transmitter connected to the modified antenna would consume one thirty-sixth of the power formerly consumed. In telephone nomenclature, an equivalent signal strength would be secured from a source 15.6 decibels lower in power level. It is thus of some economic importance to determine how an antenna may best be modified so that radiation is confined to a narrow sector within which lies the chosen direction.

Heinrich Hertz, who in 1887 and 1888 discovered means for producing and detecting radio waves, constructed the first directive antenna. Employing wavelengths of less than one meter, Hertz experimentally concentrated radio waves in a chosen direction by means of a short antenna lying in the focus of a metallic parabolic surface (Figure 2). In principle the scheme was very much like that of an automobile headlight. Hertz also observed that radio waves of the same length from different sources produced interference patterns—recurring positions of intense and feeble signal-strength—near the sources.

Parabolic reflectors similar to Hertz's experimental antenna have been employed for a number of years in short-wave radio transmission. It is essential that the dimensions of the parabolic reflecting surface be several wavelengths, and hence it is impracticable that the surface be a conducting sheet except for use at very short wavelengths. This difficulty was overcome by using a number of wires, spaced so as to outline the surface, and set at critical lengths so as to be resonant at the operating wavelengths.

Interference, well known with light waves and observed by Hertz with radio waves, is an alternative method for producing directive transmission.* If two or more narrow parallel slit-sources of monochromatic light are directed upon the same surface an interference pattern is produced, visible as a family of light and dark strips. It is brought about by the difference in phase of the radiation from the two

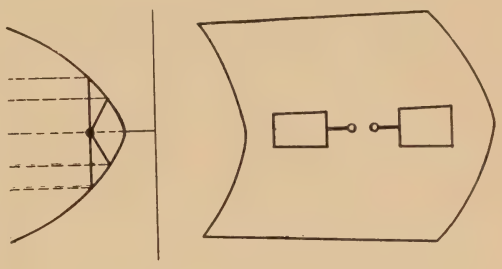


Fig. 2—Parabolic reflector employed by Hertz. The antenna is at the focus of the metallic parabolic surface

sources due to the difference in length of path between the two sources and the screen.

Directive radio transmission by means of wave interference may readily be obtained by transmitting simultaneously from the same transmitter with two or more suitably spaced antennas. If two antennas, one wavelength apart and each carrying unit current, are driven in phase, the electric intensities from both antennas, several wavelengths away in the direction normal to the two, are in phase because the paths from the antennas to the receiving point are equal. The field in this direction is the sum of the fields from the individual antennas. If, however, a direction thirty degrees from the normal is considered, the path from one antenna is one-half wavelength longer than from the other, and the time it consumes

* *The "reflectors" discussed in the preceding paragraph depend ultimately, of course, on interference also.*

in traveling this additional distance puts the radiation from one antenna one-half period behind the other. The intensities in this direction are exactly out of phase and thus the net intensity is zero. By simple trigonometry

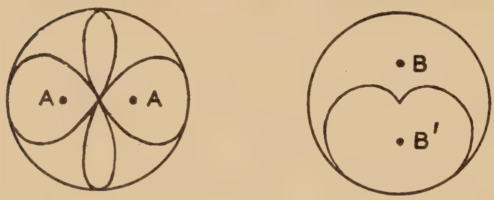


Fig. 3—Directive intensity characteristics for: (A) two antennas spaced one wavelength apart and driven in phase; (B) two antennas spaced one-quarter wavelength apart and driven ninety degrees out of phase (B leads B′)

the polar diagram of Figure 3-A may be obtained, representing the intensity in all horizontal directions about the antenna. The radii of the circle enclosing the four-leaf figure represents the intensities which would be realized if the two antennas were very close together.

Forming an example of another simple directive system are two antennas spaced one-quarter wavelength apart and driven ninety degrees out of phase with each other. Since a quarter period is consumed in traveling the distance between antennas, the radiations from the antenna which bears the current lagging ninety degrees will lag an additional ninety degrees upon arriving at the adjacent antenna, and the fields from the two antennas will cancel in this direction. In the opposite direction the fields both lag the same amount and are additive. The polar diagram for this case is given in Figure 3-B, in which again the circle enclosing the figure represents the radiations which would proceed from the two antennas if these were coincident and in phase. It has been found by experiment that two antennas will form this second system if one is driven by the transmitters and the other is parasitically excited. The parasitic antenna is usually called the "reflector antenna."

The above two schemes may be combined in several possible ways to give unidirectional systems. In general the polar diagram of the combined system may be obtained by superimposing the two diagrams and multiplying by each other the lengths of the coincident radii to obtain the lengths of the new radii.

Simple directive systems, such as

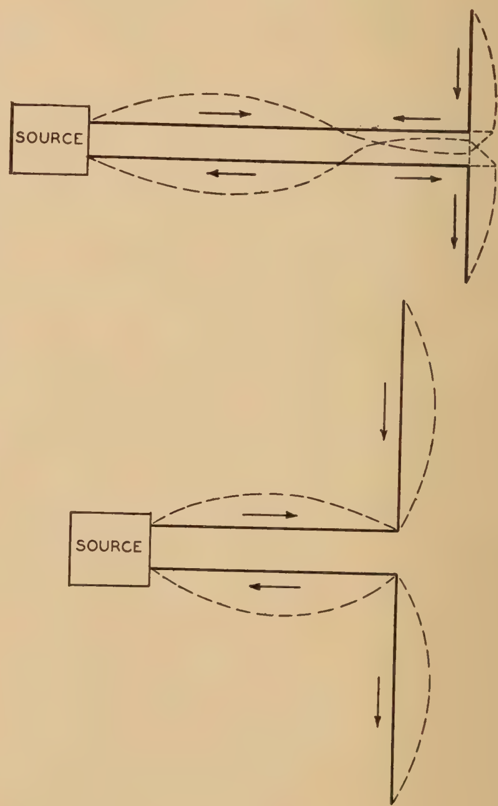


Fig. 4-A (above)—Line bent into a Hertz antenna; Fig. 4-B (below)—Line bent into two Hertz antennas

those described, were proposed by S. G. Brown in 1899 and J. S. Stone in 1901, and many others have since devised increasingly complex and more efficient schemes. Later G. A. Campbell, of the American Telephone and Telegraph Company, proposed a directive scheme comprising several rows, each bearing several antennas in suitable phase relations. He established in a general manner the relations between the spacings and phasings and devised methods whereby the performance of the system, however complex, could be predicted.

In the polar diagrams, the area of the figure, as compared to the area of the enclosing circle, is approximately proportional to the relative power consumption of the directive and the non-directive systems and thus an approximation of the gain of the directive system may be obtained by expressing the ratio of the areas in transmission units. The reason for this gain may be suggested by another simple example. If two antennas, several wavelengths apart, each have a resistance R and carry a current I, the total power consumed is $R\ I^2 + R\ I^2 = 2\ R\ I^2$. The intensity at a point where the radiations are in phase is proportional to 2 I. This same intensity could be obtained by exciting one antenna alone with 2 I units of current but the power consumption would then be $4\ R\ I^2$, or twice as much as before. In general the improvement factor of a directive antenna is nearly proportional to the number of antennas, when they are separated by more than about one-half wavelength. This is only approximately true because two antennas, when close together, react upon each other.

There are many methods for the mechanical construction of directive antennas; that now being employed at Lawrenceville depends upon the manner in which waves stand upon transmission lines. It is generally known that the current in an open-circuited line recurs along it in standing maxima

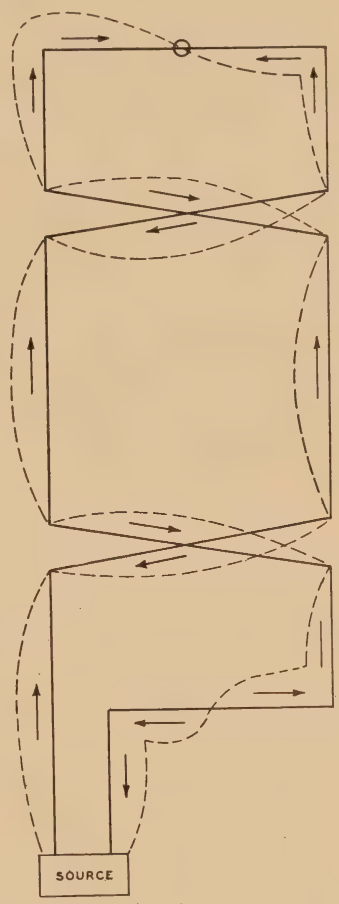


Fig. 5—A panel for the Lawrenceville antenna system. The vertical members are radiators; the crossed members are transmission-line phase shifters. The line may be open or closed at the center of the top cross-piece, since there is a standing-wave node, and thus no current flow, at that point

and minima, that the phase difference between successive current maxima is 180 degrees and that the phase difference between corresponding points

A part of the line of towers supporting the antennas

on the two wires is 180 degrees. The radiation from an open-circuited line is small, but if the ends of the line are bent outward, the radiation from these ends will be greatly augmented and the balance of the line will act largely as a means for transmitting power to the radiating end. If the bent portions are each one-quarter wavelength long, a one-half wave Hertz antenna is formed (Figure 4-A). An even more efficient antenna may be formed by bending over a one-half-wave portion of the line; in this case the bent-over portion is equivalent to two Hertz antennas driven in phase (Figure 4-B).

Thence it is only a small step to the panel arrangement of the Lawrenceville antenna system (Figure 5). Here the vertical wires are the radiating members, all excited in phase, and the horizontal pairs are transmission lines for distributing the current to the radiating elements in the desired phase-relations. The panel is equivalent to four Hertz antennas, two of which are stacked one above the other and of which the two groups thus formed are spaced one-half wavelength apart. Complete reinforcement of signal intensities takes place only in the horizontal direction normal to the panel. In all other directions destructive interference occurs; complete cancellation occurs in the plane of the panel.

By computation and by experiment it has been shown that a power improvement of four decibels is acquired from the horizontal spacing of one-half wavelength, and of two decibels from the vertical stack of two. The net power saving is approximately six decibels: the panel consumes but one-fourth the power which would be re-

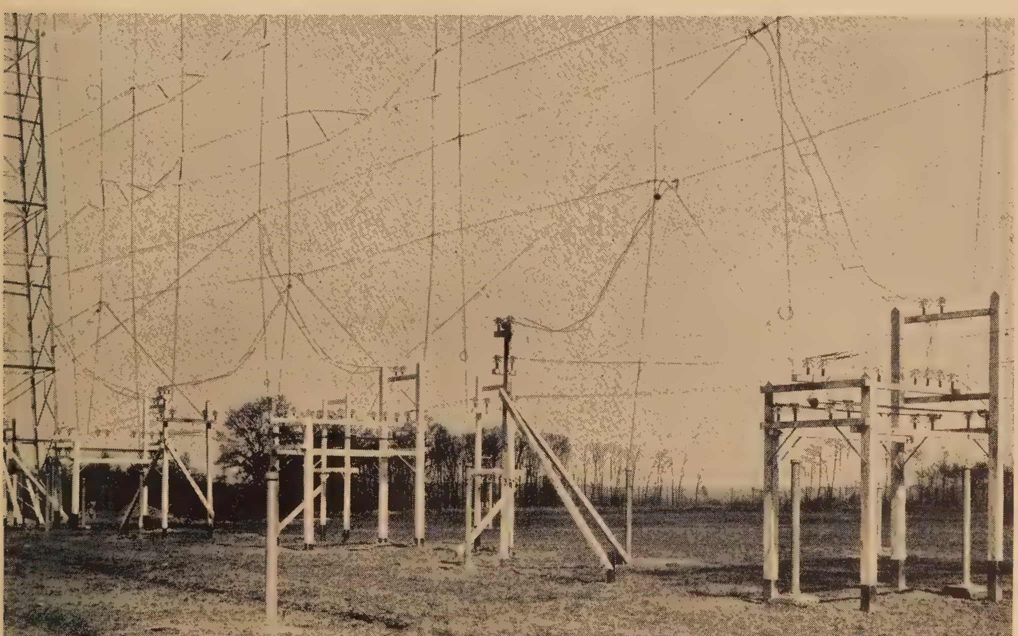
quired by one element to produce the same intensity in the chosen direction.

A second similar panel, excited parasitically, is placed one-quarter wavelength behind the first to act as a reflector and thereby create an unidirectional system. It has been found that the reflector reduces the power required to maintain a given intensity in the desired direction by approximately three decibels, and thus brings the gain of the two-panel system up to nine decibels. The two-panel system, therefore, requires but one-eighth the power which would be necessary in a simple antenna producing the same intensity in the desired direction.

Larger power savings may be effected by employing many antennas properly connected together. Practically, however, considerations of mechanical construction, investment and maintenance limit the size of the system. The complex nature of short-wave transmission also leads to a lowering of the optimum size of the antenna. For wavelengths of the order of sixteen meters, improvements of twenty decibels (a power ratio of one hundred) are practicable.

The connection of a number of antenna panels to a common feeder line must accomplish proper phase and impedance relationships. The former may readily be obtained through adjusting the lengths of interpanel lines, by tape-line measurements. The conventional methods for building up the load impedance to the surge impedance of the feeder line, however, are far from satisfactory for high-power work at short wavelengths. In this case one of the less familiar properties of a transmission line is used for transforming impedances.

If a line of surge impedance Z_0, exactly one-quarter wavelength long, is terminated with a load Z_R, the



Lower edge of antenna curtain, and frames supporting the quarter-wave lines for effecting sleet-melting connections and proper terminating impedances

sending-end impedance of the line is Z_0^2/Z_R and, if Z_R is a pure resistance, the sending-end impedance is a pure resistance. Such a quarter-wave line is employed in the Lawrenceville antenna system. Since a line bearing standing waves is being terminated at one upon which standing waves are not desired the receiving-end of the quarter-wave line is connected at either a current maximum or minimum, to ensure a resistance load.

A transmitting antenna is adversely affected both mechanically and electrically by sleet. The sleet load may strain the system to the breaking point and thus put the antenna out of service for a long period, and the mass of ice, having a dielectric constant of eighty, may detune the antenna and destroy the effectiveness of the system. Sleet is, therefore, removed in the Lawrenceville system, by heating

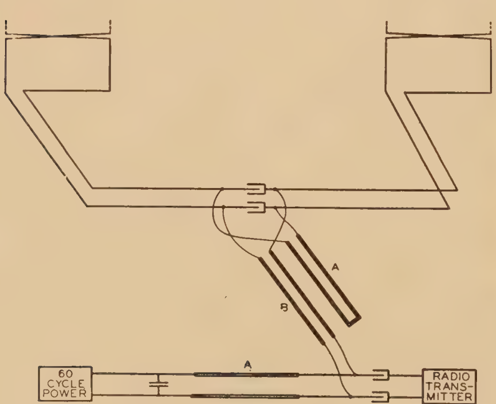


Fig. 6—Antenna connections for melting sleet from the Lawrenceville antenna

the wires with low-frequency currents of about 150 amperes at a potential of nearly a thousand volts in each antenna. All elements in the antenna are arranged to be in series for the low-frequency currents and the vertical elements in phase for the radio-frequency currents (Figure 6).

Another relatively unfamiliar property of transmission lines is utilized to effect this arrangement. If a line one-quarter wavelength long is short-circuited at the receiving end, the sending-end impedance is very large. Such

Looking down a tower line at Lawrenceville. Photo by G. M. Eberhardt of the Research Department

a line may be connected across a circuit of relative low impedance without disturbing its radio-frequency functions. From Figure 6 it may be seen that the anti-resonant circuit of quarter-wavelength bars, in combination with several condensers which readily pass radio frequencies but which block low frequencies, and in combination with two antenna panels, forms a series

circuit for the low-frequency currents and the power source. The two panels, however, are in parallel with each other and with the feeder line at radio frequencies. Both the low and the high-frequency powers may be applied simultaneously to the antenna.

For three of the four communication channels at the Lawrenceville radio plant, the antenna system is supported by a row of nineteen towers at right angles to the direction of England; for the fourth, a row of seven towers is placed at right angles to the direction of Buenos Aires. Guys run along the tops of these towers to anchors on the ground at the ends of the rows. The towers, 250 feet apart and 180 feet high, are designed to withstand the load of the largest antenna that can be supported in a bay, when covered with a coating of ice one-half inch in radius and subjected to a gale of ninety miles per hour. Each antenna occupies two tower-bays. The antenna-curtains themselves are supported by messenger cables and may be lowered or hoisted by individual winches; the curtains are constructed from No. 6 B & S wire and are held in position by insulated sections of steel harness. The several panels in each curtain are interconnected by transmission lines which lead to frames where proper connections are made and impedances built up to terminate the power leads from the radio transmitters.

The practicability of directive systems is dependent upon the shortness of the transmitted wavelengths. A twenty decibel antenna, operating on five hundred meters, would be approximately ten wavelengths or fifteen thousand feet long and two wavelengths or three thousand feet high. The investment in such a plant would probably never return dividends. Fortunately the wavelengths used in the transoceanic short-wave system are such that directive effects can economically be obtained.

High-Frequency Quartz-Crystal Oscillators

By F. R. LACK
Radio Research

IN common with many communication systems that have come into extended use in the past few years, radio channels have need for a source of frequency whose absolute value is known to a high degree of accuracy and whose relative variations are held to within very narrow limits. Such a source of frequency is used in connection with appropriate amplifiers and in some cases frequency multipliers to supply the carrier wave for the radio system.

The reasons for this rigid frequency

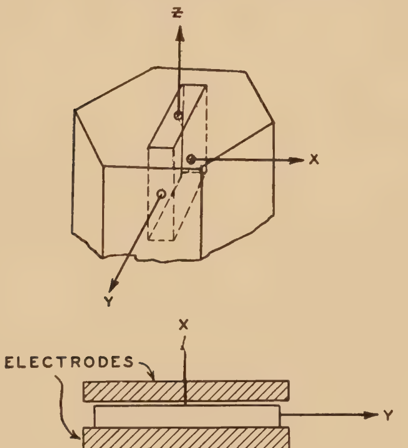


Fig. 1-*A* (*above*)—*Relation of quartz plate, used as vibrating crystal in short-wave transatlantic transmitters, to natural crystal from which it is cut. Fig.* 1-*B* (*below*)—*Relation of quartz plate to electrodes*

specification are obvious to everyone who has used a radio receiver whether for broadcast reception or otherwise. Absolute accuracy and freedom from slow variations of large magnitude are necessary to keep the station at the assigned position in the frequency spectrum and thus avoid interference. Rapid variations must be eliminated if good quality is to be maintained at the receiver.

The usual means employed for frequency generation in the telephone art consist of a vacuum-tube oscillator in which the electric oscillations set up in a tuned electric circuit are sustained through the medium of a vacuum tube. The frequency of such an oscillator is affected by a number of factors, such as supply voltages to the tube, the load impedance, the temperature of the circuit elements, and the like. The frequency change of this oscillator as ordinarily set up is greater than a tenth of one per cent for a one per cent change in plate battery voltage. The modern operating requirements for a radio station require a constancy of five thousandths of one per cent or better, taking into account all the factors that affect the frequency. This oscillator is thus unsuitable for carrier frequency generation without some radical improvement in stability.

A large amount of experimental and theoretical work has centered about the stabilization of vacuum-tube oscillators for supply-voltage and load-impedance changes and a number of circuit arrangements have been devised which result in a material improvement. Some of these schemes involve the balancing of one disturbing factor against another, while

others make use of phase-correcting networks. The most desirable scheme from the standpoint of simplicity uses a circuit whose reactance and resistance change very rapidly with frequency. This implies a sharply resonant circuit — that is, one with very low damping. Such a system can accommodate itself to a new set of conditions, such as changes in tube-supply voltages or load impedance, with a small frequency change, to an extent depending upon how much the damping has been reduced.

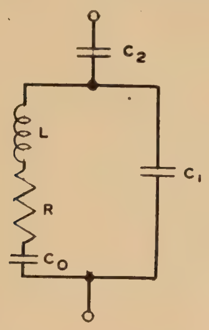


Fig. 2—Circuit electrically equivalent to quartz crystal vibrating in a normal mode

A good measure of the reduction of damping is the ratio of the inductive reactance of the circuit element to its resistance. For well-designed coils this ratio may be as high as three hundred, but mechanical vibrators can be constructed whose equivalent ratio of reactance to resistance is of the order of 30,000. If, then, a mechanical system can be used for the oscillator circuit, a hundred-fold improvement in damping is to be expected with a corresponding increase in frequency stability.

The use of mechanical vibrating systems in frequency generation is not new. The classical example is, of course, the clock pendulum; the clock is a frequency generator whether it delivers electrical impulses or not. There are also numerous applications of tuning forks, driven by vacuum tubes, as frequency standards.

With these mechanical vibrators some means must be provided for transforming the mechanical vibrations into electric oscillations and vice versa. With the tuning fork the transfer is usually accomplished magnetically. This form of coupling is satisfactory for low frequencies, but for frequencies much above ten kilocycles the hysteresis and eddy-current losses tend to defeat the very purpose of using a mechanical system. Moreover at higher frequencies the physical size of the vibrator becomes so small that it is difficult to couple to it.

The use of mechanical vibrators was confined to the low frequencies in the audible range until Professor Cady of Wesleyan University pointed out that the piezo-electric effect in crystals could be used to furnish the necessary coupling mechanism at the higher frequencies. The term "piezo-electric effect" describes that property of a certain group of crystals by which electric charges are generated on particular surfaces when the crys-

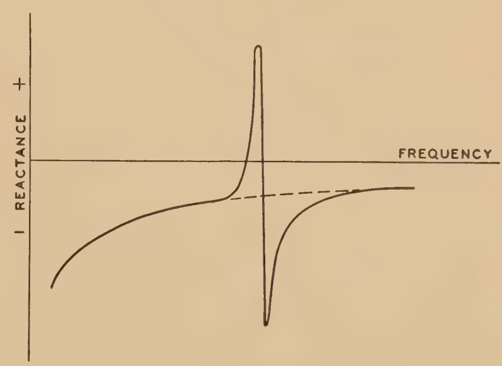


Fig. 3—Reactance-frequency characteristic of a quartz vibrator. The dotted line, for a simple capacity, coincides with the vibrator characteristic except in the region of the vibrator's normal mode

tal is stressed mechanically. Of this group of crystals there are only a few which possess the mechanical qualities necessary for a standard of frequency. Quartz is the most suit-

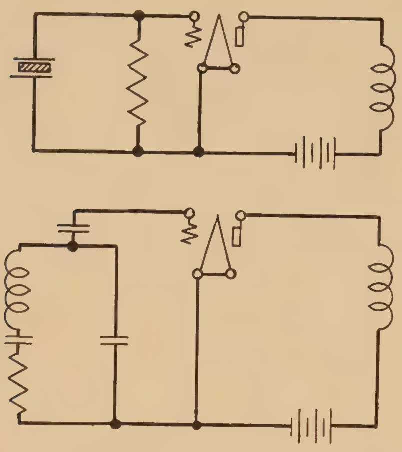


Fig. 4-A (above)—Typical electromechanical oscillating circuit incorporating a quartz crystal. Fig. 4-B (below)—Circuit electrically equivalent to 4-A

able of these because it is easy to obtain at a reasonable cost, offers no serious difficulties in preparation and has very low electrical losses.

Quartz-crystal vibrators can be constructed for any frequency from a few kilocycles to ten megacycles but the ordinary useful commercial limits are from fifty kilocycles to six megacycles. As usually prepared, the vibrator consists of a plate or bar cut from the quartz crystal. Coupling to the element is secured by means of metallic electrodes placed in light contact or in close proximity to the major faces of the quartz. Figure 1-a shows such a plate in its relation to the original axes of the crystal structure (as cut for use at Lawrenceville), and Figure 1-b illustrates the relative position of quartz plate and electrodes.

The process by which the plate is set in vibration can be described briefly as follows. When a potential is applied to the electrodes, the crystal plate, by reason of the piezo-electric effect, expands in the direction Y and contracts along the direction X. Along the third direction Z of the plate, which corresponds to the direction of the optic axis of the crystal, there is no motion. When the potential is removed, the crystal contracts and develops a voltage of opposite sign on the electrodes. For a steady potential, the magnitude of this effect is small: of the order of 6×10^{-7} centimeters for a potential of 3000 volts. But when an alternating potential having a frequency corresponding to one of the mechanical vibration frequencies of the plate is applied, the familiar phenomenon of resonance builds up the amplitude of vibration to a level at which the forces acting are very considerable. The motion of the surface is sometimes so violent that the crystal "walks" around between the electrodes, and it is not uncommon for a crystal to shatter when vibrating.

The equivalent circuit of a quartz vibrator in the region of one of its mechanical vibration frequencies, or "normal modes" of vibration, is shown in Figure 2. The elements L, R and C_0 represent the electrical equivalent of the mechanical vibrating system. C_1 is the capacity of the plate itself—of a condenser with the quartz plate as the dielectric. C_2 is the capacity of the air-gap between the quartz plate and the electrodes. For a million cycle vibrator, L may be of the order of a half a henry; R, 100 ohms; and C_0, C_1 and C_2, 0.06, 1.0 and 5.0 micromicrofarads respectively. The reactance curve of such a system is shown in Figure 3; except

in the region of a mode of vibration, the crystal acts as a simple capacity.

High-frequency crystals are usually used in a circuit similar to that shown in Figure 4-a. The equivalent electrical circuit of this arrangement is shown in Figure 4-b. This type of circuit will only oscillate when the equivalent circuit element on the grid side is an inductive reactance, and, as the crystal is only an inductance in the region of its mechanical period, oscillations can only take place at the natural frequency of the crystal.

Assuming that the low damping of the crystal system is sufficient to reduce the frequency change with change of supply voltages and load impedance to a negligible amount, there are other factors which affect the frequency which have to be considered. Among these are the temperature of the quartz plate and possible change of position of the plate with respect to the coupling electrodes. To take care of these factors the crystal has to be held at a fixed temperature and so supported in the holder that it is free to vibrate but cannot change its position relative to the holder.

The designer of a frequency generating system involving a quartz plate, therefore, must know: the relation between the dimensions of the plate and the frequency at which it will vibrate; the decrement of that vibration; its temperature coefficient of frequency; the type of vibration; and finally the fact that the voltage developed by the plate while vibrating will be adequate to insure sufficient coupling between the mechanical and the electrical systems. If a crystal plate could be so cut as to respond to only a single frequency, it would be simple to determine this information for this mode of vibration and write the complete specification. Unfortunately specification is not as straightforward as this.

In the first place, any mechanical system of three dimensions possesses a large number of degrees of freedom. The crystalline nature of quartz further complicates its vibration, for the various elastic constants in a given direction vary as that direction changes with respect to the axes of the crystal structure. As a result, a quartz plate has a large number of possible modes of vibration, some of them within a few hundred cycles of each other. The frequencies of these modes depend upon the orientation of the plate with respect to the crystal axes and the shape and ratio of dimensions of the plate. The decrement, temperature coefficient, voltage developed, and the like, are all functions of the particular mode of vibration set up in the crystal and sometimes have values that are widely different for modes of vibration that are of very nearly the same frequency. Moreover, a slight change in temperature or a variation in the circuit to

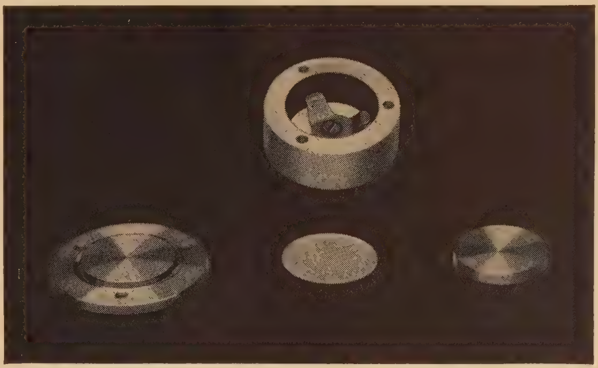


Fig. 5—Quartz crystal and its holder, of the type used at Lawrenceville, disassembled

which the crystal is attached will sometimes cause the crystal to hop from one of these modes of vibration to another.

There has been a large amount of work done, both in these Laboratories and by other investigators, on the factors that determine the relative frequency spacing, activity, and other constants of these modes of vibration. The scope of this article does not permit any comprehensive summary of the result of these studies; hence it will be only noted in passing that it is possible so to cut a plate with respect to the crystal axis, and so to adjust the ratios of the dimensions of the plate in cutting, that certain definite modes of vibration have enhanced activity and thus predominate. These modes of vibration will have a predictable temperature coefficient of frequency.

Such crystals are now being produced on a commercial basis. Figure 5 shows one of these crystals designed for frequencies above two megacycles, with its associated holder. This is the type of crystal now in use in the Lawrenceville short wave radio transmitter. In these crystals the vibration utilized is that which takes place along the direction of the thickness of the plate. This vibration has a temperature coefficient of approximately ninety cycles in a million per degree centigrade, and will develop sufficient voltage to drive a 211-type tube.

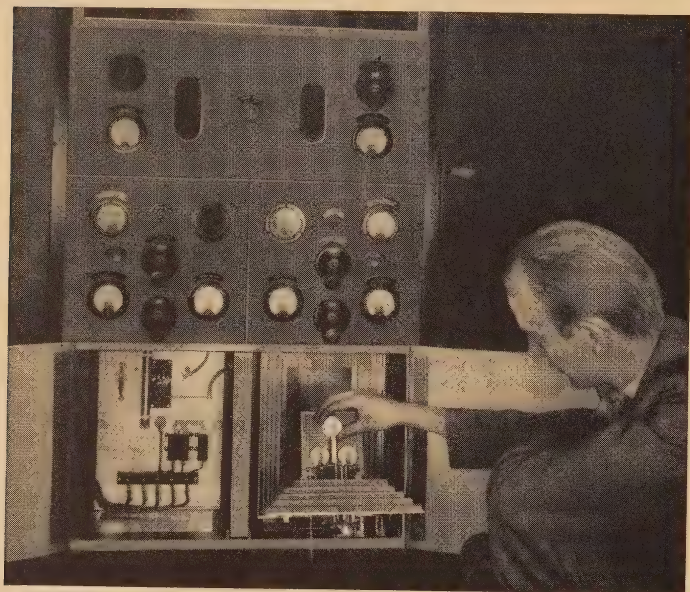


Fig. 6—A. Oxehufwud examining one of the Lawrenceville crystal-installations

At Lawrenceville, three of these crystals are mounted in one oven unit. These three crystals provide the three base frequencies, all in the neighborhood of three megacycles, which are stepped up by succeeding circuits to the three operating frequencies of the station. The crystal holders are fastened to a copper block mounted in a heat insulated container (Figure 6).

The temperature of the block is regulated by means of a heater and resistance thermometer buried in the block. The thermal inertia of the copper acts as a filter and prevents the temperature cycles at the heater from reaching the crystals. The resistance thermometer forms one element of the Wheatstone bridge of a Leeds & Northrup recording thermometer. Contacts provided on this recorder are so adjusted that current to the heater in the block is turned off when the temperature goes beyond fifty de-

grees Centigrade. By this means the temperature is held at this level to within one-tenth degree Centigrade. This Leeds & Northrup recorder not only controls the temperature but makes a printed record of variation.

In changing frequency, the desired crystal is connected to the grid of the crystal-oscillator tube by a switch on the front of the oven. Since it takes an appreciable time to warm a crystal to fifty degrees C., the complete crystal oscillator including oven and crystals is provided in duplicate, to avoid a shut-down in case of crystal failure.

This crystal oscillator installation is typical of the modern application of these mechanical vibrators. Of the means now known for securing accurate frequency control, the quartz crystal appears to be the best. As telephone and radio requirements become more rigorous, the application of crystals will doubtless be extended. By resort to harmonic and sub-harmonic generation, the frequency range to which crystal control can be applied becomes virtually unlimited.

Vacuum Tubes for Use at High Frequencies

By H. E. MENDENHALL
Vacuum Tube Research

WHEN transmission studies showed that carrier frequencies of the order of thirty thousand kilocycles would play a part in transatlantic communication, investigations were immediately undertaken to determine the type of vacuum tubes most suited for transmission systems operating at such high frequencies. It was found that the vacuum tubes which had met the requirements of the transmission systems of the long-wave service, using a carrier frequency of the order of seventy-five kilocycles, were unsuited for short-wave systems. Such tubes could not be operated in parallel at the high frequencies; and, even when used singly, they were extremely short lived unless operated at considerably reduced plate voltages and output powers. There are several reasons why tubes that were structurally satisfactory for the low-frequency range were inadequate for the high-frequency range.

In the first place, at the high frequencies the inter-electrode capacity of the elements of the tube becomes very important from the circuital standpoint. The "charging" or displacement currents which flow through every dielectric in an alternating electric field increase with the frequency of the alternations. These displacement currents heat the various dielectrics whose power factors are not zero, used in and around the tube, thereby causing the ultimate failure of the tube. A "high" vacuum is the only perfect dielectric, for heat is not developed in it through dielectric losses. It can fail only when leaks or a slow evolution of gas from the parts

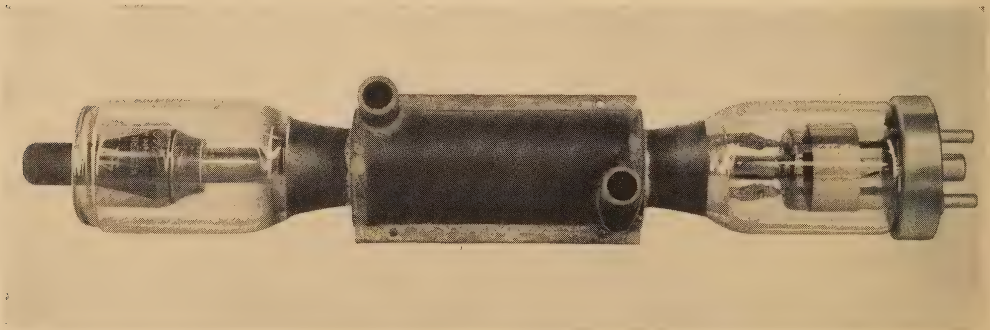


Fig. 1—Western Electric 240-A tube, to handle ten kilowatts of high-frequency power. The grid lead is at the left; the filament leads are at the right; the plate is the copper cylinder in the center surrounded by the jacket for cooling water

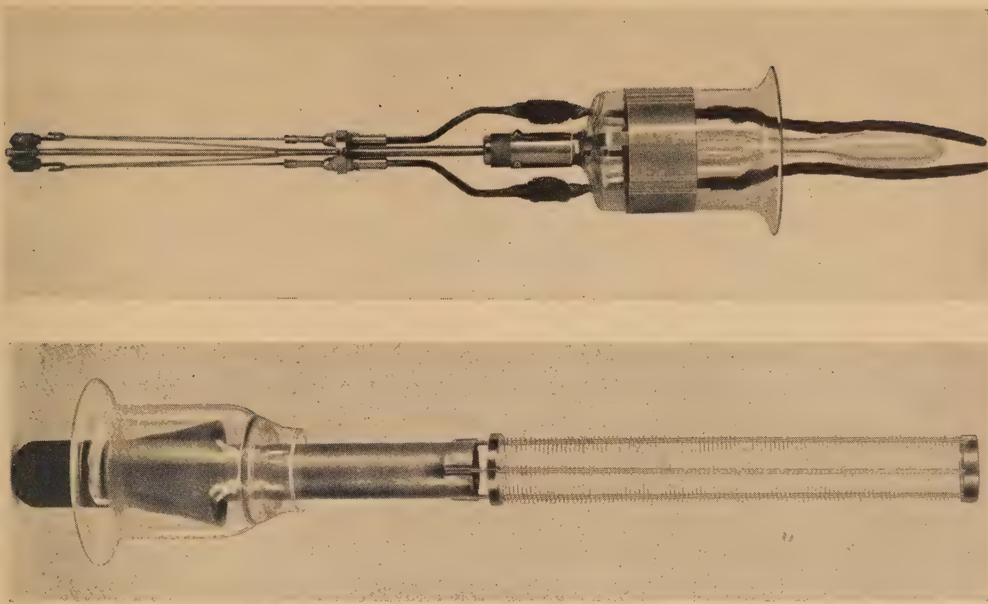


Fig. 2—Filament (above) and grid (below) structures of the 240-A tube

of the tube change both its status as a vacuum and its insulating properties. The air separating the elements on the outside of the tube will be only about one-tenth as effective an insulator when the tube is oscillating at thirty thousand kilocycles as compared with the non-oscillating condition, when the same plate potential is applied to the terminals. The same air gap will be disrupted, moreover, by one-twelfth of the applied voltage if it be alternating at thirty thousand kilocycles instead of at sixty cycles.

Another reason for the failure of earlier types of vacuum tubes when used in short-wave circuits is to be found in the "skin effect." A high-frequency current passing through a conductor is forced to travel through a very thin layer at the outside of the conductor. The effective size of the conductor is thus reduced, its resistance correspondingly increased, and overheating engendered.

In view of such facts as these, new tubes had to be developed and old types modified to work with the new circuits. M. J. Kelly suggested several years ago that water-cooled power-amplifiers for short-waves be made double-ended: with the filament structure and leads supported on glass at one end, a water-cooled anode in the middle, and an oversize grid lead supporting the grid structure from the glass on the other end. In this construction a maximum of insulating glass and air separate the leads to the tube elements, and the leads can be made large in "skin" area.

Preliminary models of water-cooled tubes embodying these features were made in the laboratory and these models were supplied for transmission development work at Deal Beach. While this work was in progress, development activities were directed toward the final commercial design of water-cooled tubes so constructed. Such tubes were standardized and made available for the transoceanic short-wave service.

One of these tubes is shown in

Figure 1, and its filament and grid structures in Figure 2. It is the Western Electric 240-A vacuum tube, with an output rating of ten kilowatts in the high-frequency transmission range. Its present form has been reached after many cycles of change in the development process.

This tube was designed to meet short-wave circuit requirements, and then adopted after experimental tubes had weathered a long series of severe tests conducted by C. E. Fay. The circuit used for these tests consists of a shielded push-pull oscillator. A heavy straight lead, tapped in the center with a grid leak, connects the grid terminals of two 240-A tubes under test, which are mounted vertically on Pyrex insulators. The anodes are connected by means of a water-cooled coil, about eight inches in diameter, of three turns of copper tubing. The capacities of the tubes between grid and plate complete the oscillating circuit. The load is applied by shunting a small section of the inductance coil with hollow water-cooled carbon rods. The temperature rise and the volume of the cooling water supplied to the rods give a measure of the total power output. By means of these tests, the power limits of the tube are determined.

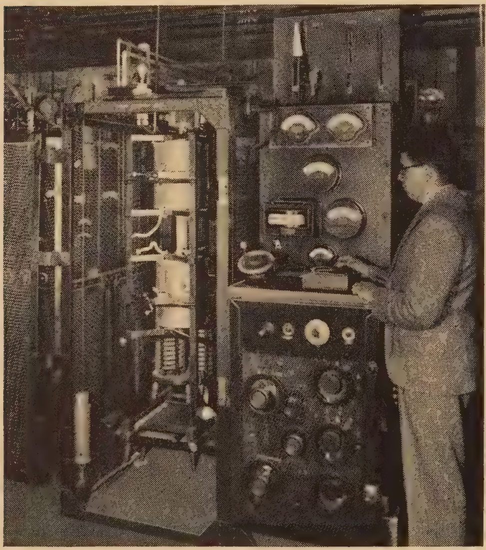


Fig. 3—Pumping station for outgassing and evacuating 240-A tubes, attended by C. W. Koons

Minute as are the capacitances between the test circuit and other unrelated circuits in adjacent rooms, the frequency of the testing currents is so high that considerable amounts of power can be transferred across the intervening space. In spite of radio-frequency chokes in the high voltage lines of the test set, and the shielding afforded by enclosing the whole circuit in a large aluminum case, enough high-frequency energy passes by displacement currents through the holes in the shielding for electric and water-supply lines, to upset galvanometer readings, reverse manometer microammeters and burn out thermocouples in adjoining laboratories. The tests are, therefore, conducted out of hours.

Another interesting phase of the development has been the technique used by C. W. Koons for evacuating tubes of this style. He appears in Figure 3, standing beside a high-voltage pump station and pumping a 240-A tube. The tube is supported on insulators at the middle, and has special ovens fitted over both glass ends. The grid, filament, anode and glass parts are outgassed simultaneously by heating each of these parts to the highest temperature which it will stand and still keep its form. The evacuation process consequently becomes a relatively short one, as compared with that for other water-cooled tubes whose various parts must be outgased separately. The water jacket becomes an integral part of the tube after it has been pumped.

In order that these tubes may be operated successfully in parallel, without singing at still higher frequency, their characteristics and thus their construction must be as nearly alike as possible. V. L. Ronci has been responsible for the mechanical design, and with A. I. Crawford for the manufacturing specifications, of these tubes. His group, in collaboration with the Development Shop, has built machines (one of which is shown on page 52) resembling lathes but with fires for their tools. On these are made the glass-to-copper seals for the filament and grid leads and for the anodes. Glassblowers are still necessary for assembling the parts in their proper alignment—one of the most important steps in the manufacture. The skill and experience of such men as J. J. Heil and H. W. Ericsson make pioneering in large vacuum tubes possible.

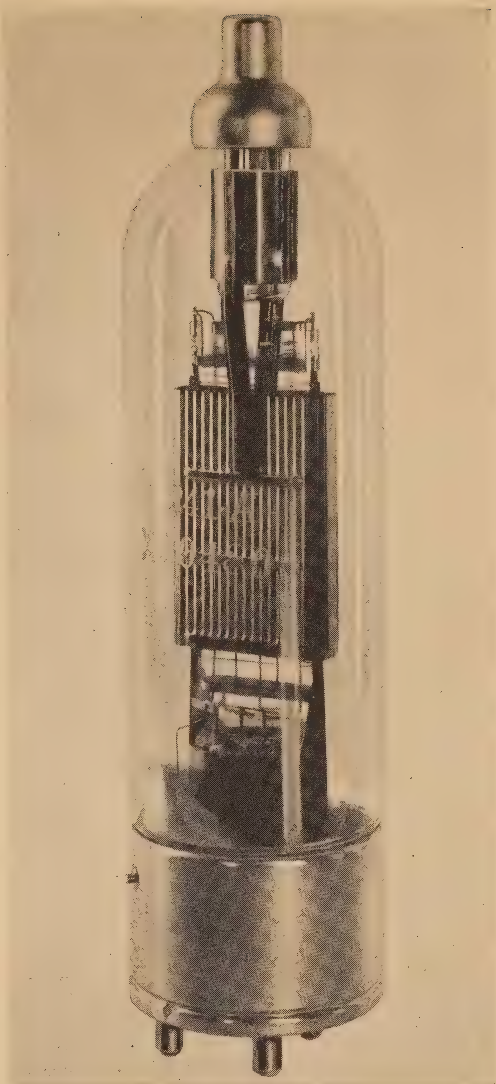


Fig. 4—250-*watt double ended tube of the* 241-A *type*

Figure 4, a picture of the 241-A tube, shows how the 212-D 250-watt tube had to be redesigned as a double-ended tube to make it suitable as an amplifier in the earlier stages of short-wave radio-telephone development. The 243-A, another member of the vacuum-tube family, is exactly similar in appearance to the 240-A but has only one-half its filament capacity. It is rated at two kilowatts and has been used to drive the 240-A tubes.

Since April 1, the Tube Shop at Hudson Street has been making these double-ended tubes at a rate sufficient to supply the needs of the short-wave radio transmitters, and they are performing fully up to expectations.

The Radio Receivers

By F. A. POLKINGHORN
Radio Research

THE function of the radio-telephone receiver is to select the desired signal, to amplify it, and then to detect or demodulate the signal so that its voice-frequency components may be sent over a telephone line to a subscriber.

The problem of selecting the desired signal to the exclusion of others is a major design problem. A directive antenna system serves to discriminate to a considerable extent between signals arriving from different directions, but to only a slight extent between the desired signals and others closely adjacent in frequency. The receivers built for the short-wave transoceanic channels are of the double detection or "superheterodyne" type. This type was chosen because it is well adapted to give a high degree of selectivity desired, and to provide the large amplification required with a minimum of trouble from regeneration or singing.

Each transmitter and receiver of the transatlantic circuits must be capable of operating on any one of three frequencies in the range between 9,000 and 21,000 kilocycles in order that the operators may pick a frequency upon which transmission is good at any particular time. At the receiving station each receiving unit consists of three antennas and a receiving set. The antennas are located several hundred feet apart so that they do not influence one another. At each antenna there is a circuit which aids in obtaining the desired direc-

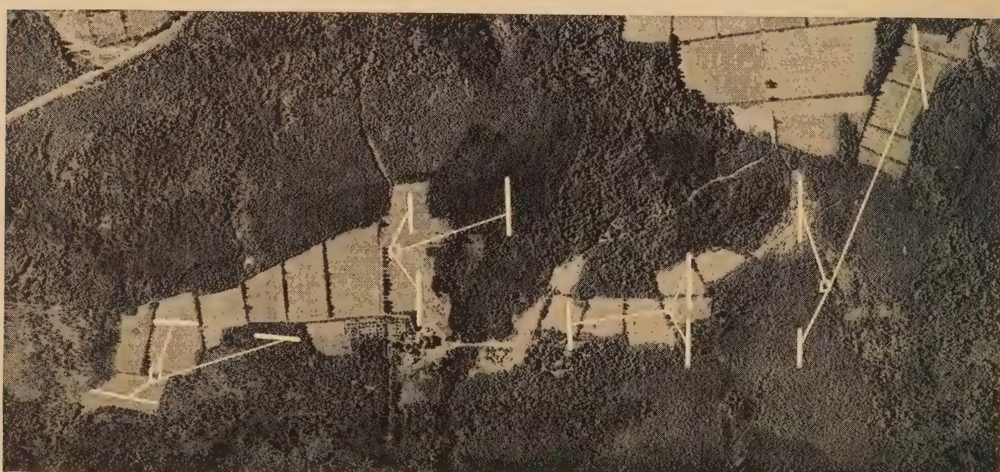


Fig. 1—Airplane view of Netcong, N. J., showing locations of receivers (as white squares), antennas (as heavy white lines), and antenna transmission lines (as light white lines)

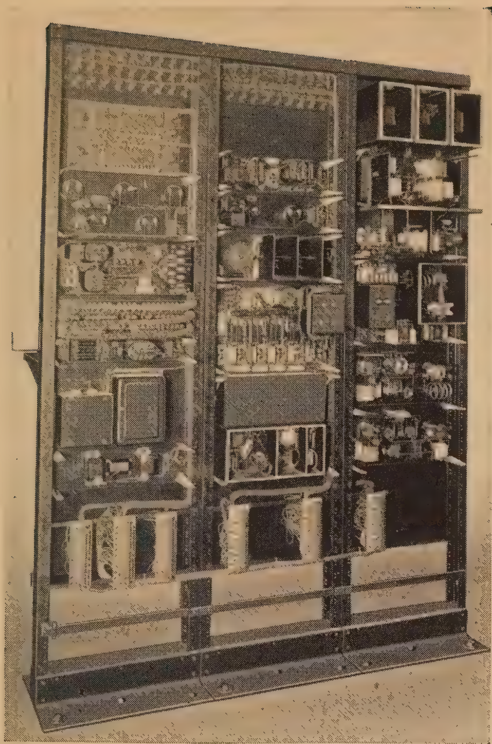


Fig. 2—Rear view of a receiver

tional characteristics from the antenna and acts as a transformer to connect the antenna to the transmission line leading to the receiver. This transmission line, formed by copper tubes, one within the other and separated by insulating rings, is supported a few inches above the ground. It follows a sinuous course, with bends to allow for expansion and contraction under temperature changes.

The receiver has three antenna circuits which are always connected to their respective antennas and to the grids of three screened-grid vacuum tubes of the 246-A type. A switch in the plate circuits of these tubes determines which of the antenna circuits is to be used at any one time. An additional stage of screened-grid amplification is then used.

The incoming signals next reach the first demodulator where they are combined with another frequency such as will give a beat, or intermediate, frequency of 400,000 cycles. For example, if it is desired to receive a frequency of 18,310 kilocycles, the beating oscillator of the receiver is adjusted to either 17,910 or 18,710 kilocycles. Either of these frequencies when combined with the received frequency of 18,310 kilocycles gives a beat frequency of 400 kilocycles. This intermediate frequency is then passed through a narrow band-pass filter. Six additional stages of amplification

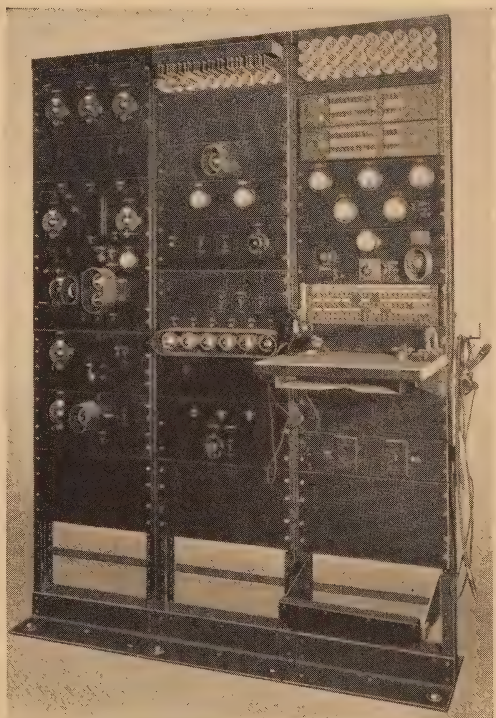


Fig. 3—Front view of a receiver

follow the filter. An attenuator is inserted between the first and second stages for control and measuring purposes. Another band-pass filter is used to connect the last amplifier to the second demodulator, where the speech frequencies are reproduced.

Fig. 4—General view of a receiving antenna

One stage of voice-frequency amplification brings the speech-level to that required for transmission over the cable to the central terminal building, where the speech is further amplified and sent over the line to the transatlantic operator in New York.

When received at any single point, waves of the frequencies used on these channels are subject to wide fluctuations of intensity, probably because the waves proceed over several different paths to the point, and there aid or oppose each other in a random manner.* This fading causes the voice-frequency output of the receiver to vary somewhat periodically at frequencies between once every few seconds and many times a second. Such changes in volume are quite disconcerting to a subscriber and consequently an automatic gain control has been included in the receiver to minimize this trouble.

The automatic control acts to change the gain in the receiver in inverse proportion to the strength of the received signal, thus causing the output level to remain substantially constant. This is accomplished by using an additional amount of intermediate-frequency amplification in an auxiliary amplifier, rectifying the output of this amplifier and applying the rectified output voltage as additional bias on the grid of the first demodulator. An increase in the received signal tends to increase the output of the rectifier which, when applied to the grid of the first demodulator, decreases its efficiency and greatly reduces the rise in output volume of the receiver over what would otherwise be obtained.

The appearance of these receivers is quite different from the ordinary receiver used for broadcast reception. Since the receivers are an integral part of the telephone plant, standard telephone construction was used as far as was practical. All apparatus is mounted on brass panels which are in turn mounted on relay racks. The panels are faced with mats of furniture steel to hide the numerous screw holes necessary for mounting

* *H. T. Friis*, BELL LABORATORIES RECORD, *July*, 1928.

the many small parts in place. Fuse panels provide protection for all plate and filament circuits. In addition each plate circuit is provided with a protective lamp.

Any filament or plate current may be read by inserting a short-circuiting plug into the corresponding jack in a jack strip, and thus connecting one of the meters on the meter panel into the circuit through an auxiliary fuse. This means may be used to keep the set in operation while replacing a fuse. A dummy plug placed in a jack will open its circuit; an external meter may be plugged into a circuit by means of a cord.

Telephone and telegraph facilities for use of the operator are mounted directly on the set. Head receivers and a monitoring coil are provided so that the operator may monitor the circuit when required. A volume indicator is constantly connected across the output of the voice-frequency amplifier. By observing the volume indicator and the meters connected in the second demodulator and rectifier a good idea of how the set is operating can be obtained at any time. A high-frequency oscillator and an intermediate-frequency oscillator are included in the receiver so that the set may be completely adjusted, and the adjustments be readily checked, without the aid of a received signal.

For all tubes "filament-failure lamps" are provided, which give a red indication when a filament fails. Since there are a large number of tubes of four different types in the set, a name plate is used to designate each tube position and the type of tube to be used in that position.

Shielding, to prevent regeneration in the high-frequency and auxiliary gain-control amplifiers, is provided by the mats, parts of which are hinged on certain panels to form doors opening into compartments behind the panels where the tubes and circuits are placed. Throughout the design of the receiving equipment every effort has been made to ensure convenient and reliable operation in routine commercial use.

Receiving Antennas

By E. BRUCE
Radio Research

IMPROVEMENTS in any point-to-point radio system should be made first at those places where a given overall result is least costly to secure. In particular the effect of increasing the power of a transmitter can equally well be secured by improving the effectiveness of either the transmitting or the receiving antenna. The expense of high-power transmitters is very great, and the designer of receiving antennas can command a considerable working budget without being underbid by the designer of transmitters.

The design of receiving antennas is important for other reasons as well. An apparently irreducible minimum of noise is inherent to the input circuits of the first vacuum tube* of the radio receiver. To override this noise, increased antenna efficiency, through directivity, becomes the most fruitful means of increasing the signal "pick-up." When static rather than internal noise is the limiting factor, antenna directivity again accomplishes an improvement. Signal waves come from a rather definite direction toward the receiver; static disturbances, on the other hand, come from nearly all directions at random. The directional receiving antenna, responsive only in the direction from the transmitter, takes full advantage of the desired signals, but discriminates against all static disturbances except those which approach the antenna from the responsive direction.

An antenna will develop directional properties if it is built up of distinct wire-segments or "elements," and if these elements are spaced apart by a suitable and fairly large fraction of the wavelength of the signal which the antenna is expected to pick up. Only with the use of "short waves" did it become economically practicable to build systems large enough compared with the wavelength to take advantage of this directivity. The short-wave transatlantic antenna employs a row of equi-spaced elements, identical in their phases and power levels. This form of antenna is often termed "broadside," as it is maximally active to waves proceeding perpendicularly to the row of elements.

There are numerous ways of so interconnecting spaced elements as to obtain specified phase and power relations; the way most suitable for commercial use is, of course, that which necessitates least adjustment and which accomplishes the desired directivity with the simplest structure. A long wire can be folded back and forth in space in a simple manner to give the desired phase relations for "broadside" directivity. If the attenuation along it is negligible, the elements will all have equal power levels with reference to all points of the antenna.

* *The cause and effect of the random voltage fluctuations which occur in resistances are discussed by J. B. Johnson in the* RECORD *for February, 1927.*

Such a structure is shown in Figure 1. The lengths of the vertical elements, and the spaces between them, are one-quarter of the length of the signal wave which the antenna is expected to pick up. Such a wave, traversing the antenna, induces in the vertical elements voltages which are equal but whose phase relations depend on the direction of approach of the wave. In analyzing the behavior of the antenna, these electromotive forces may be represented by lumped voltages at the central points of the verticals.

Each lumped voltage can be supposed to cause in the wire a succession of electrical disturbances whose sense and magnitude depend on the sense and magnitude which the voltage has at the successive instants. The disturbances successively originated at a voltage source can be regarded as passing out along the wire in both directions from the voltage source, as two trains of disturbances which retain their senses and magnitudes. The passage of such a train constitutes a current. When two currents passing in the same direction are composed of disturbances which correspond in sense at all points, the two reinforce each other. When, however, the disturbances composing two currents passing in the same direction are of equal magnitudes but opposite senses, the two cancel.

Thus from each source of voltage electrical disturbances will pass both to the receiver and to the open end of the antenna. Those proceeding to the open end will be reflected there and will thence in turn pass, with magnitudes unchanged but with senses reversed, to the receiver. Maximum reception will occur when the signal wave approaches in such a direction that the voltages it induces in the antenna produce disturbances which are additive on reaching the receiver. No reception will occur when these disturbances cancel at the receiver.

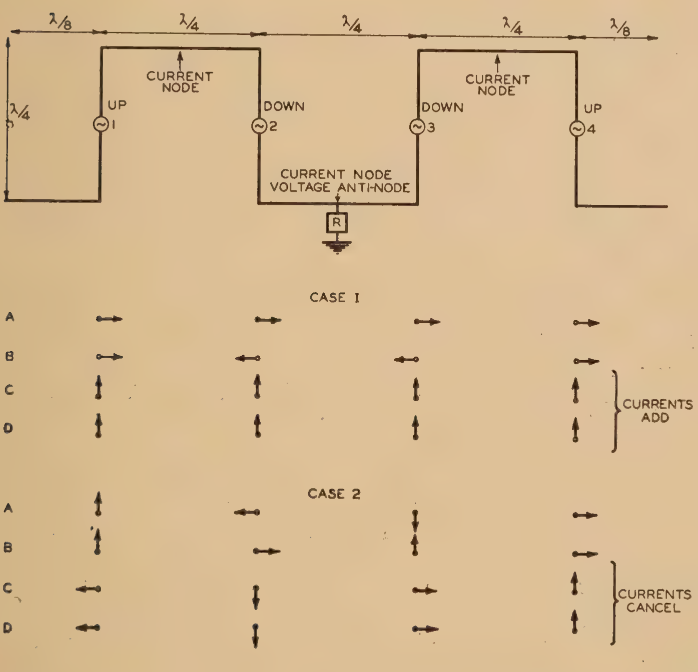


Fig. 1—Behavior of broadside antenna to broadside (Case 1) and end-on (Case 2) waves. The vectors are drawn below the elements whose electrical effects they represent. A—space voltages; B—wire voltages; C—currents in R (directly propagated); D—currents in R (by open-end reflection)

When the signal wave is proceeding broadside to the antenna, it induces in the vertical elements voltages which are identical in phase from the

standpoint of the plane of the verticals. Figure 1, Case 1, shows in row A voltage vectors drawn below the elements to represent the voltages at a particular instant. The manner of connecting the verticals, however,—alternately at their upper and lower ends—vitally distinguishes between the voltage phases viewed from the plane standpoint and from the wire standpoint. When the vertical elements and their horizontal connections are regarded as one continuous wire, the folding in space effectively alternates the voltage phases of the successive vertical elements of the wire, for either side of the receiver R. These voltage vectors are shown in row B.

At each source of voltage, similar voltage vectors recur with a frequency equal to that of the incident wave. Since one wavelength is the distance between sources of voltage whose voltage vectors are simultaneously similar, each disturbance propagated in either direction arrives at the next similar voltage source exactly one cycle later. Thus the disturbances propagated in either direction reinforce one another. The currents proceeding toward the receiver do so in phase and produce an additive effect. Their current vectors appear in row C. Those proceeding toward an open end likewise do so in phase, and are there reflected back toward the receiver with their component disturbances reversed in sense. Since the total current reaching the open end travels a quarter-wavelength from the last voltage source to the end and an equal distance back to that source again, a half-cycle elapses between the two visits. But the reflected current of reversed disturbances finds there on its second visit a reversed voltage, propagating a reinforcing current The reflected currents, therefore, proceed toward the receiver in phase with, and thus adding to, the directly propagated currents. These current vectors appear in row D. Altogether it is evident that the antenna is in this case making the most of all its currents for the benefit of the receiver.

When, as in Case II of Figure 1, the wave approaches the antenna end-on—at right angles to the broadside wave of Case I—the antenna acts with very different effect upon the receiver. In Case I any one part of a signal wave traversed all elements of the antenna simultaneously; in Case II it traverses them successively. Alternate sources of voltage, which are a half wavelength apart in space, are a full wavelength apart along the wire. Thus any part of a signal wave which has induced a voltage in an element will reach the next-element-but-one through space a half cycle before the disturbance it caused in the first element, proceeding in the same direction, can reach the new element through the wire. The disturbance proceeding in the opposite direction will reach the next-element-but-one a cycle and a half after the part of the wave which produced it has passed that element. This is the time of the signal in advancing a half wavelength through space plus the time of the disturbance in returning a full wavelength through the wire. When either disturbance reaches the next-element-but-one from its source, a later part of the signal wave will be inducing an equal but opposite voltage in that element. The resulting disturbance will be equal and opposite to the arriving one and will cancel it. All currents, therefore, in either direction in the antenna will annul one another, so

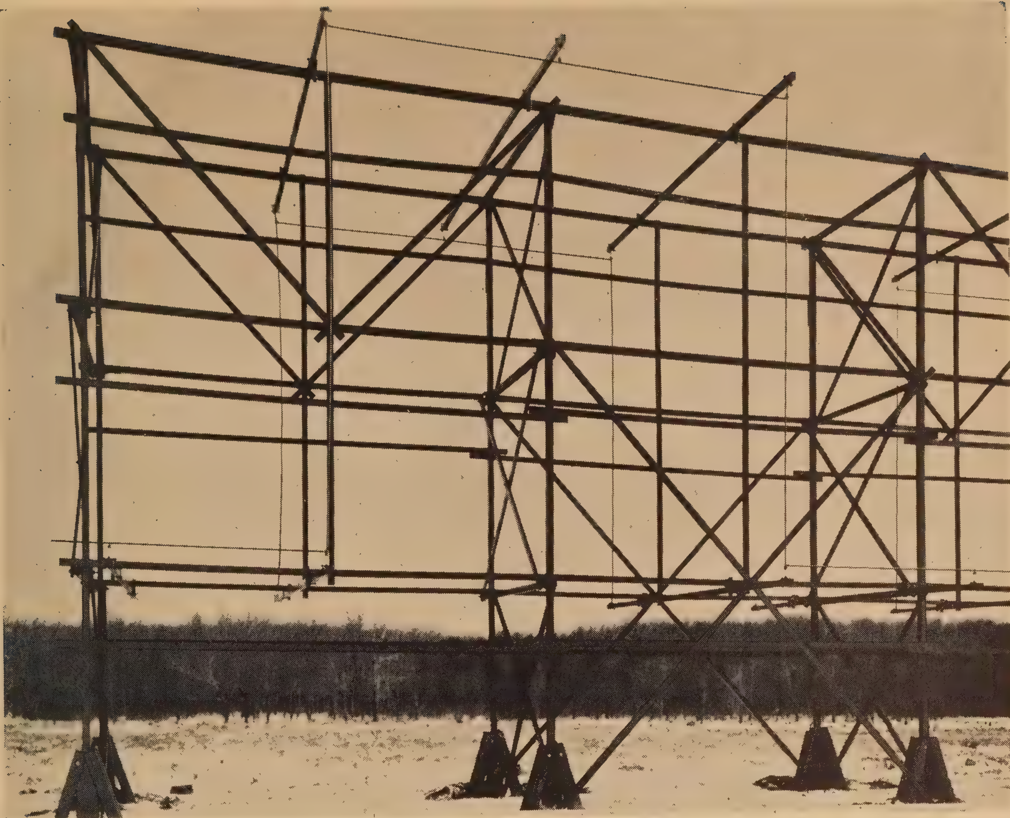


Fig. 2—One end of a short-wave directional receiving antenna at Netcong, N. J.

that the receiver will not be energized.

This antenna, accordingly, has maximum sensitivity to a broadside wave (from either direction) and no sensitivity to an end-on wave. To waves of intermediate direction it has intermediate sensitivity. Relative sensitivity can be plotted against direction in a polar diagram to show the sensitivity-characteristic of the antenna.

A valuable feature of this antenna is that it does not permit the currents induced in its vertical elements to suffer loss through reradiation from its horizontal elements. Such loss could be accomplished only by the passage of the currents along the horizontal connections. Due to the plurality of voltage sources, the electrical disturbances add in such a way that the current is in standing waves. Fixed current nodes occur in these standing waves at each multiple of a half wavelength measured from the open end: at the centers of the horizontal elements. Thus the net value of current in each horizontal is small at all times and is composed of disturbances which at either side of the node are opposite in sense. In directions perpendicular to the horizontals the radiations from the opposite currents cancel, at any appreciable distance. In other directions the fact that the currents are small and opposite makes radiation negligible. The symmetry of the antenna either side of R, moreover, causes the antenna to act as a whole about R in the same manner as

do the horizontal elements about the current nodes. This symmetry further assures cancellation of horizontal radiations.

Figure 2 shows one of the broadside antennas constructed at Netcong, New Jersey, for reception from England. It contains, in each of the two rows, twenty-four elements spaced a quarter wavelength apart. As was shown before, a single row does not discriminate between broadside waves from opposite directions. To avoid the bi-directional characteristic which a single row would exhibit, the second identical row is spaced a quarter wavelength behind the first and so connected with it that the two differ in phase by a quarter period. The resulting undirectional characteristic is shown by the plot in Figure 3.

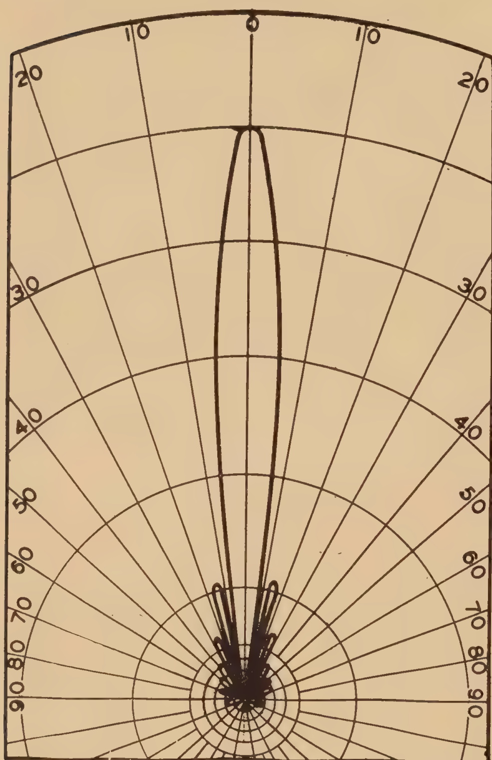


Fig. 3—Directional characteristic of Netcong antenna

A broadside antenna of this size delivers to the receiver a power greater by nearly forty times (sixteen decibels) than that delivered by a single, vertical, half-wave antenna. If static were distributed uniformly around the antenna, the improvement in the ratio of the signal power to the static power would likewise be nearly forty fold. When discrimination against directional static can be effected by use of the deep minima in the directional characteristic, still greater improvements in the signal-to-static ratio are possible. The variability in the apparent direction of received waves* is of course a major factor in limiting the degree of directivity which it is useful to attempt. Within this limitation directional receiving antennas accomplish great increases in the efficiency of point-to-point radio systems operating on short waves.

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* Bell Laboratories Record, *July*, 1928, *page* 359.

Voice-Frequency Equipment

By J. A. COY
Equipment Development

TO the telephone subscriber who calls a European city from the United States, the procedure is no more complicated than with any toll call, and the connection is not noticeably different. Nor from the point of view of the toll operator is the radio telephone circuit much unlike ordinary toll circuits. Like them it may be connected to local subscribers over switching trunks of the usual type or extended to distant subscribers over other long distance toll circuits.

A few unusual features there are, to be sure. One is that each radio telephone circuit is given the full attention of a "channel operator" at each end throughout the period when commercial service is being given. This insures intensive use of the circuit and prompt attention to any difficulty the subscribers may experience in carrying on a conversation. "Report operators" take care of getting subscribers ready to talk, setting up connections to distant cities, and timing the calls. Tickets and other operating information are passed by telephone typewriter in the intervals between calls, to insure accuracy of record and aid in the efficient use of circuit time.

Beyond the operating room, however, the radio telephone presents many unusual features of physical plant, personnel and procedure. By radio frequency two voice paths are established across the ocean, one path carrying the voice in one direction, the other path in the opposite direction, and both terminating at locations advantageous for radio transmission and reception. They are extended at each end by voice-frequency land line or cable to the city selected as most convenient for making connection to the telephone system of the country and there, united in a single circuit for two-way transmission, are terminated with other toll circuits in the toll switchboard. This general scheme differs from the four-wire operation common with toll cable circuits principally in the wide separation of the one-way paths, in the equipment provided for the suppression of echoes and singing, in the arrangements made for continuous manual gain-control and in the close attention given to the system by a special organization of personnel.

In cable operation the one-way paths are kept in the same toll cable and pass through the same intermediate offices. In radio telephone practice the requirements governing the location of radio transmitting and receiving offices make it desirable to separate these offices by considerable distances. The west-to-east radio path of the long-wave transatlantic circuit is from Rocky Point, Long Island, to Cupar, Scotland, the east-to-west path from Rugby, England, to Houlton, Maine. From these transmitting and receiving offices voice-frequency lines extend the circuit to New York and

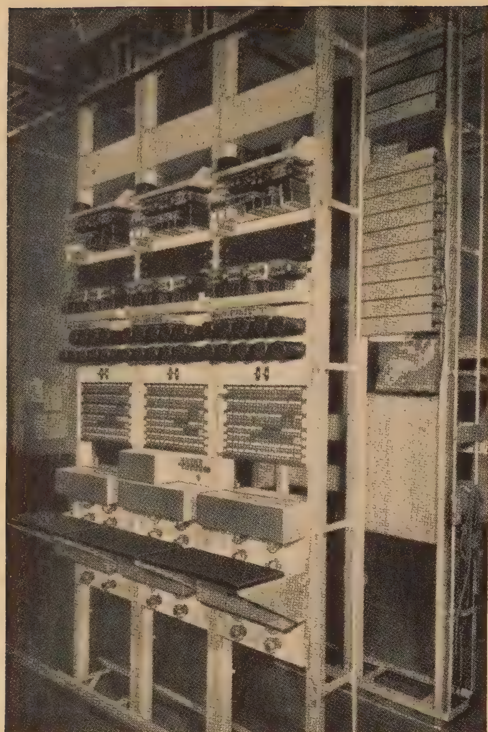


Fig. 1—Vodas relay equipment at Walker Street

London. Circuits established more recently and using short-wave radio transmission have their transmitting and receiving offices, at the American end, at Lawrenceville and Netcong, New Jersey, respectively. They likewise are extended to the Long Lines building at Walker Street, New York.

The tendency for strong echo currents to exist in the radio telephone circuit is considerably greater than in toll cable circuits. The equipment provided at each terminal to interrupt the paths which these echo currents tend to follow is commonly termed the "vodas", from the initial letters of its name, "voice operated device, anti-singing." It has been described in detail and compared with the simpler echo suppressor used on cable circuits, in a previous article.* The latest type of this equipment is shown in Figure 1.

To aid in over-riding the noise frequently found in the radio links, it is desirable that the radio transmitter operate fully loaded on all conversations. This is accomplished by the manual adjustment of gain control equipment by a technical operator at each terminal. Monitoring at the terminal, receiving and transmitting offices is for the most part done through amplifiers which take from the line an amount of energy too small to affect its operation and amplify this energy to a volume which will be satisfactory

*"*Echo Elimination in Transatlantic Service,*" *by G. C. Crawford,* Bell Laboratories Record, *November,* 1927.

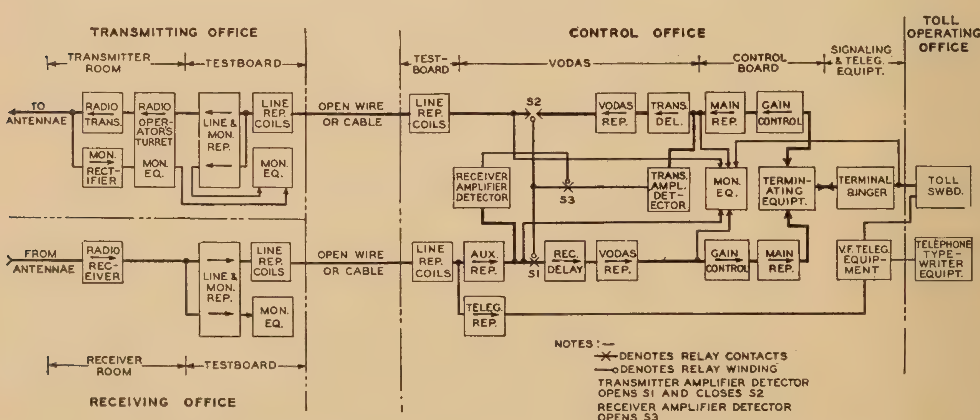


Fig. 2—Schematic diagram of voice-frequency equipment

in an ordinary telephone receiver.

The voice-frequency equipment filling these requirements is schematically presented in the diagram of Figure 2, which shows that used at one end of a radio link. This equipment is divided among the toll operating office, the control office, the radio transmitting office, and the radio receiving office. Although the figures and the following description apply in detail only to the American equipment, the foreign terminals are generally similar.

At the control office are provided a testboard, common to the office; a control board, individual to each radio circuit; a vodas likewise individual; signaling and telegraph equipment, and (not shown in Figure 2) transmission measuring and order wire equipment.

The testboard consists of three bays, shown in the frontispiece.* The bay on the left of the group contains the repeating coil and jack equipment which terminates the land lines from the receiving office and permits the patching out of a defective line with a good one. The bay on the right carries similar equipment for lines from the transmitting office. In the center bay are terminating and patching jack equipment for the telegraph order wires to the receiving and transmitting offices and answering jacks for the telephone order wires to these offices, to the various control boards and to the toll switchboard. On the keyshelves of these bays is located equipment for talking and monitoring on the land lines and order wires and for testing lines and equipment for the location of faults.

At the control board, the technical operator watches the radio telephone circuit continually to insure that transmission is satisfactory. Conveniently

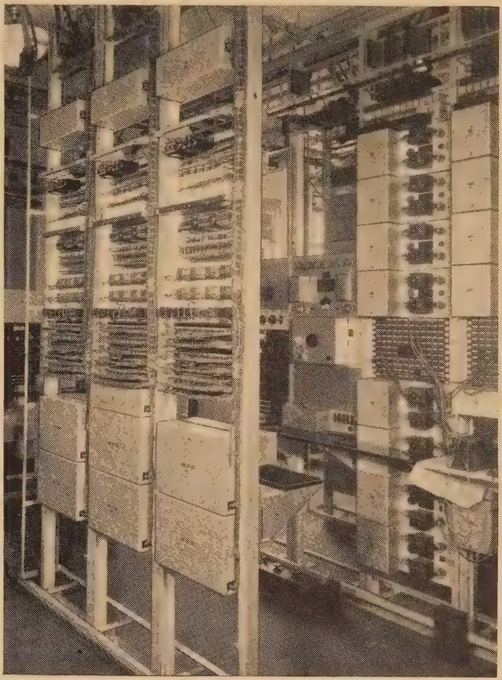


Fig. 3—General view of vodas relay and telephone repeater equipment at Walker Street, taken during installation and test

located in a panel just in front of him are meters which indicate the volume of voice energy going out on the transmitting path and of that coming in on the receiving path. In the same panel are dial-operated potentiometers which he adjusts from time to time to bring these levels to the desired value. Most of this adjustment is on the outgoing path and is required to compensate for variations in the energy coming from a local subscriber or over a toll line from a distant city and for strong or weak talkers, so as to maintain constant energy level at the

* *The illustration on Title (page 1) is a picture taken in the Long Lines Building at Walker Street, and shows, left to right: the three control boards, monitored by T. P. Bruno, Long Lines Department, W. F. Malone, Trial Installations Group No. 4, W. F. E. Droese, Long Lines Department, the testboard, attended by J. Nedelka, Trial Installations Group No. 2; and a unit of transmission measuring equipment.*

radio transmitter. The technical operator can also without leaving his position adjust the sensitivity of the vodas to obtain satisfactory operation with variations in the condition of the radio telephone circuit and of connected toll circuits. Monitoring amplifiers and keys permit him to monitor at any of the five points on the circuit indicated in Figure 2, to determine whether the equipment is functioning properly. By telephone order wires he can communicate with the operator at the toll switchboard or with the testboard man in the control office, and by telegraph order wires with the radio transmitter operator at the transmitting office or the radio receiver operator at the receiving office. The terminating equipment, indicated in the sketch, is located at the top of one of the bays of the control board. This equipment joins the one-way paths for connection to the switchboard, informs the toll operator when the circuit is ready for use and in the case of the long-wave channel, sets up the equipment for telephone typewriter service when the operator connects this apparatus at the switchboard.

The telephone repeaters associated with the terminating and vodas equipment are not located with them but are placed in a separate group as in a toll cable repeater office (Figure 3). Five repeaters of the type standard for four-wire cable circuits are required per radio telephone circuit. They are wired uniformly and provided with patching jacks so that they can be used interchangeably and so that a spare unit can be quickly inserted in place of a defective one.

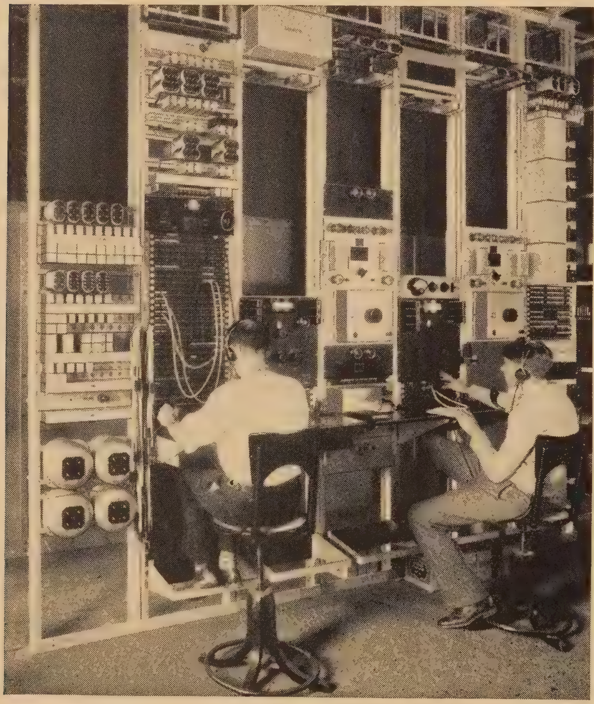


Fig. 4—Line terminal equipment in its copper-shielded room at Lawrenceville, attended by D. B. McKey (left), Technical Employee, and H. T. Ashworth, Radio Man, of the Long Lines Department of A. T. & T.

The terminal ringer equipment and the voice-frequency telegraph equipment are quite similar to that used on toll cables, and the telephone typewriters are similar to the commercial type used generally in the Bell System.

At the testboard, the telephone repeater group and each control board, there is provided a unit of equipment for making transmission measurements. This unit consists of a transmission measuring set of the type standard for cable repeater offices and an oscillator, variable in frequency throughout the voice range. At the control board the technical operator uses this equipment to measure the transmis-

sion efficiency of the radio telephone circuit as a whole, and to check the efficiency of any part of the circuit when unsatisfactory overall transmission is found. The testboard man uses his set for measurements on the land lines, and the repeater man his for measuring the gain of the repeaters. The two latter sets serve also as reserve units for use at the control board in case of trouble in the regular sets there.

At the transmitting office, as indicated in Figure 2, the voice-frequency equipment is divided between the testboard and the transmitter room. The testboard itself consists of one bay of equipment of the same nature as that in the testboard at the control office. Associated with it are one or more bays of telephone repeaters, and a regular and reserve unit of transmission measuring equipment similar to those at the control office. One telephone repeater per circuit is required to make up for the losses on the land lines. The testboard bay, repeater bays and transmission measuring equipment, together with a fuse panel and small distributing frame, are located in a room which is completely shielded with sheet copper on floor, walls and ceiling (Figure 4). The doors are lined on one side with copper so arranged as to be in contact with the wall shielding when the door is closed and the windows are covered with permanent copper-mesh screens. This shielding keeps out of the voice-frequency equipment radio-frequency energy which would otherwise be picked up from the nearby transmitting antennas.

In the radio transmitter room the voice-frequency equipment is placed in a copper-shielded turret mounted on an ordinary desk (Figure 5). This turret contains facilities for switching the radio circuit from a regular to a spare trunk from the testboard,

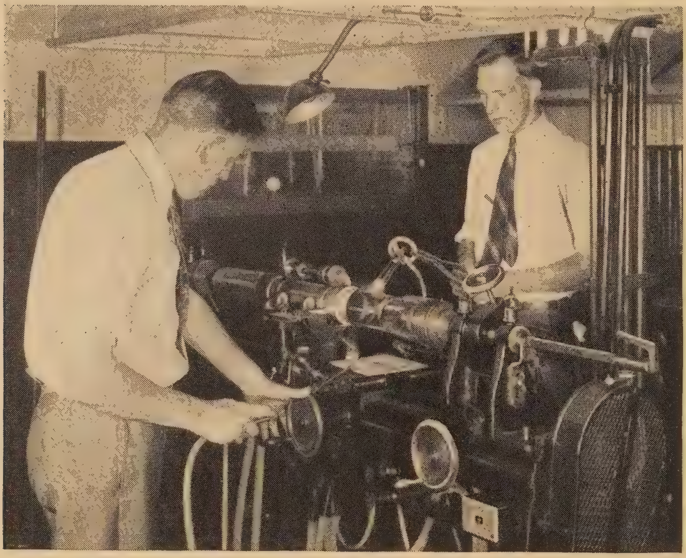
Fig. 5—C. W. Millard, Radio Man, of the Long Lines Department, at the control desk and turret in the transmitting room at Lawrenceville

equipment for monitoring on the circuit and for measuring speech-energy levels, and terminating equipment for a telephone order-wire to the testboard and for the telegraph order-wire to the technical operator in the control office. There are also provided tones of 300 cycle, 1000 cycle and 2700 cycle frequencies of standard testing power, for making approximate measurements on the transmitter. The tone apparatus, although considered part of the voice-frequency equipment, really pertains to the operation of the radio link.

The voice-frequency equipment in the receiving office is very similar to that at the transmitting office. The trunks to the receivers appear in the

receiver bay itself instead of in a turret.

In general the equipment used for the voice-frequency portion of the radio-telephone circuits conforms with the usual standards for toll system equipment. Standard nineteen-inch relay rack bays of the channel iron type are used. The methods of cabling and wiring are standard except that, due to unusual variations in transmission level through the various bays, somewhat more than the usual amount of shielded wiring is employed. To a large extent standard types of apparatus, such as telephone repeaters, transmission measuring sets, oscillators and telephone sets, are employed with no internal modification and with the least possible modification in external wiring as compared with their ordinary uses.



J. J. Heil and H. W. Ericsson making copper-glass seals in high-power vacuum tubes (see page 37)

Power Supply for Voice-Frequency Equipment

By J. L. LAREW
Equipment Development

POWER requirements for the voice-frequency circuits of the short-wave transatlantic service are rather severe. Not only must the voltage of the supply be regulated within close limits but the current furnished must be free from disturbing components and all interference between power supply and the talking or radio circuits must be eliminated. Even slight sparking at contacts a considerable distance from the radio receivers may interfere with satisfactory reception.

Power must be supplied at three separate locations: one for the control room in the Long Lines building at 24 Walker Street; one for the short-wave receiving station at Netcong, New Jersey — some thirty-five miles west and north of New York City; and one for the transmitting station at Lawrenceville, New Jersey — about fifty miles southwest of New York. At all of these points direct current is required at low-voltage for filament supply, and at a higher voltage for plate potential; but the actual voltage and methods of control differ somewhat depending on local conditions.

Motor-generators or some form of alternating-current rectifiers are used for charging the batteries. The outputs of all of these charging sources have small alternating-current components, and to reduce these to negligible values filters using electrolytic condensers are required.

These are of the form recently adopted for central offices, which has already been described in the RECORD.* They are built of aluminum cell condensers, which supply large ca-

* BELL LABORATORIES RECORD, *April*, 1927, *page* 276.

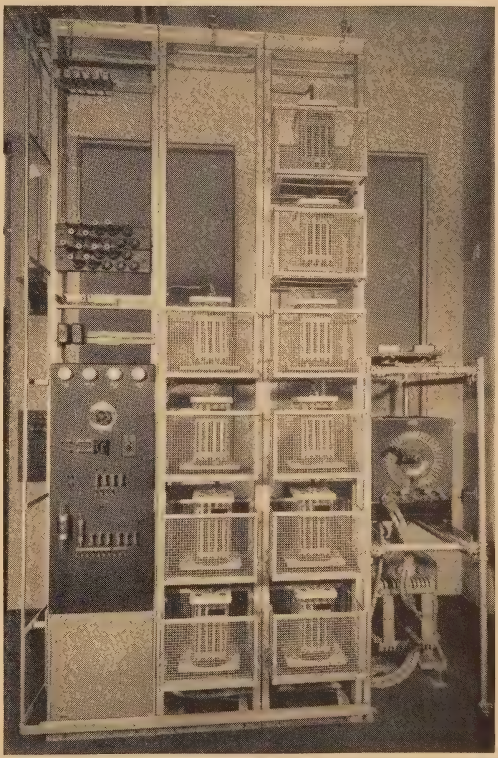


Fig. 1—Automatic voltage regulating equipment for 24 volt, and filtering equipment for 24 and 130 volt, power supplies at the control office at 24 Walker Street

pacitances in a minimum of space, and of iron-core choke coils. Several cells are connected in series or in parallel depending on the voltage or capacity required, and the complete filter may be built in one or two stages. A single stage consists of a choke coil in series in the line, and a group of condensers bridged across the line. A two-stage filter has a second combination of choke coil and condensers connected to the circuit in the same manner as, and immediately adjacent to, the first.

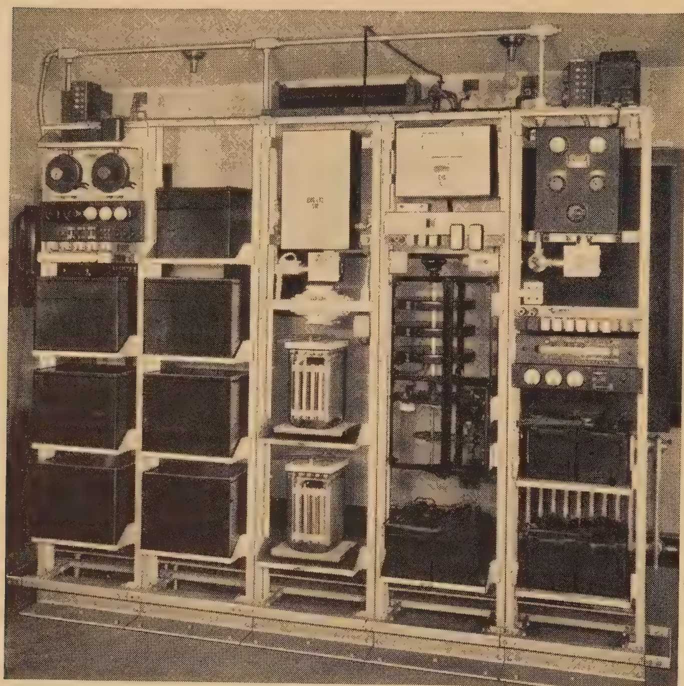


Fig. 2—Power supply equipment for both filament and plate supply at the Netcong receiving station

At the control office, low voltage power is obtained from the battery supplying the dial office in the same building. The voltage of this source —maintained at $23\frac{1}{2} \pm 1\frac{1}{2}$ volts— is not sufficiently constant for the use of the repeaters and other vacuum tube equipment used for the transatlantic service, so that additional regulation is required. This takes the form of a motor-operated rheostat, connected in series in the main feed line, and a voltmeter relay which indirectly operates the motor to cut in or out resistance as required. The resulting voltage at the distributing point is maintained at $20\frac{1}{4}$ volts with a variation of only $\pm\frac{1}{4}$ volt.

The plate supply is obtained from a battery (also used for other purposes) in the same building. Its voltage is maintained at 130 ± 5 volts; and as this is satisfactory for the vacuum tube plates no further regulation is needed. A two-stage filter is used with this supply, however, but only a single stage for the low voltage.

In addition to these two power sources, a third is required at the control office for operating the telegraph circuits used by the technical operator in communicating with both the receiving and transmitting stations. This supply is at 260 volts with a third wire tapped at the middle point of the battery. By this means 130 volt positive and negative impulses may be sent over the telegraph circuits.

All the power equipment, except the voltage regulator for the low voltage supply and the choke coils, is mounted on the three-bay relay rack shown in Figure 1. At the left is a

panel mounting the various fuses, switches, and meters required, and on the two bays to the right are the electrolytic condensers for the filters. Two condensers are connected in series for the 130 volt supply so that four are required altogether for the two stages. Three condensers are connected in parallel for the low voltage filter—one set on each side of the choke coil.

On the floor to the right of the relay rack is the 300 ampere choke coil used in the low voltage supply; immediately above it is the motor operated rheostat; and above this are the choke coils for the two-stage 130 volt filter. These are long coils of small diameter and low current capacity, and are almost hidden by the insulators and pipe.

On the wall to the left of the relay rack is the voltmeter relay for the voltage regulator and below it a panel of spare fuses.

At the Netcong receiving station the power plant differs somewhat from that at the control office because both batteries and charging equipments must be provided. These plants are located in a shielded room, lined completely with copper, and in addition auxiliary devices are provided on the power plants to prevent radio interference.

The arrangement of the equipment is shown in Figure 2. Two bays at the left contain a standard 604-B power plant for the plate supply. This equipment has already been described in the Record.* It includes its own filtering arrangement so that no external condensers or choke coils are required. The remaining three bays contain the low voltage supply. In the center bay are two electrolytic condensers used for the filter; and the associated choke coil rests on the top of the racks. In the top section of this center bay is an emergency lighting switch which automatically connects several lamps—conveniently located around the building—to the 24 volt battery in case of failure of the outside supply.

The low voltage supply equipment in the last bay on the right is designed for a load of ten amperes. Additional bays—each of ten amperes capacity—may be added up to a total load of thirty amperes without exceeding the capacity of the motor-driven rheostat. This maintains a voltage of $24 \pm \frac{1}{4}$ volts—$3\frac{3}{4}$ volts higher than that of

* Bell Laboratories Record, *March,* 1929, *page* 287.

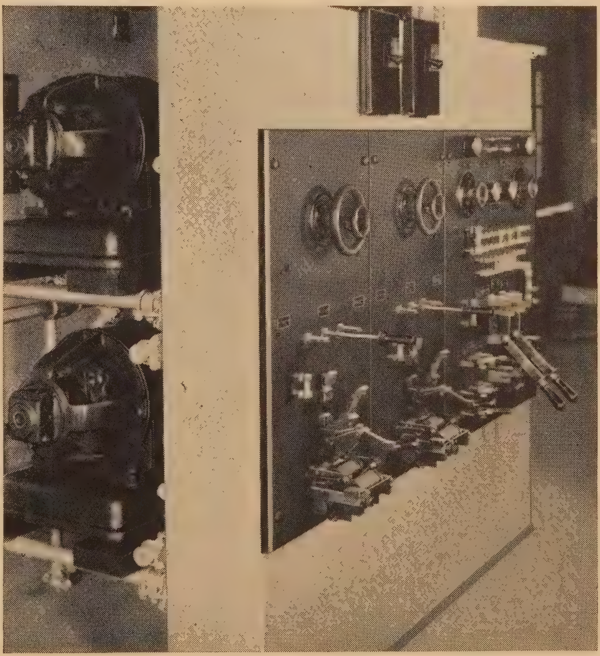


Fig. 3—*Low voltage power supply equipment for the Lawrenceville transmitting station*

the control office at Walker Street. The rheostat for voltage regulation is in the second bay from the right.

At the Lawrenceville transmitting station the various radio channels are housed in two buildings known as buildings No. 1 and No. 2. The plate power supply in building 1 is exactly like that of the receiving station at Netcong except that the spark quenching and shielding apparatus is not required because of the lesser sensitiveness of the transmitting equipment. No storage battery plate supply is used in building 2 as dry cells are adequate for the small needs of the voice-frequency equipment; all the line terminal equipment is in building 1.

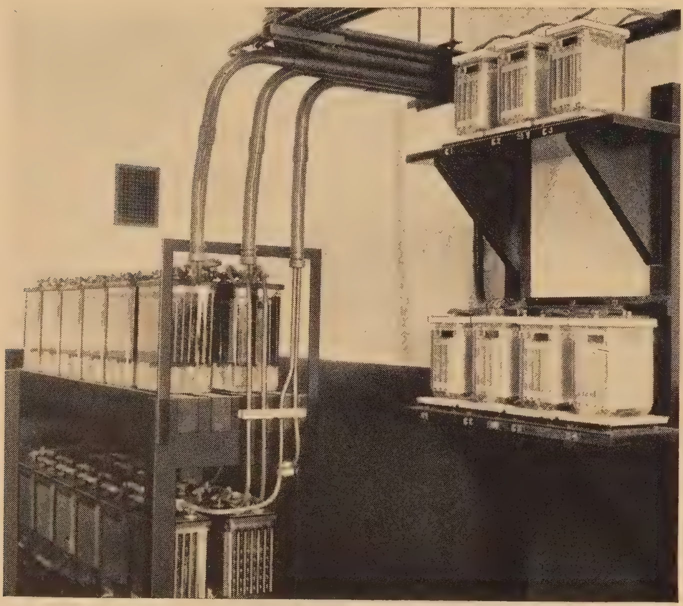


Fig. 4—Battery room at the transmitting station showing duplicate 24 volt batteries and the electrolytic condensers for both 24 and 130 volt supplies

The equipment for low voltage supply is the same for both buildings. Two 75 ampere motor-generator sets—one used as a spare—are mounted one above the other on a pipe frame work. In front of and fastened to this frame are the generator control panels and an associated battery control panel as shown in Figure 3. Choke coils for the filter used for the low voltage supply are mounted on the frame with the motors but do not show in the photograph.

Duplicate batteries of eleven cells each are provided in a separate room. Here also are grouped the electrolytic condensers for the filters as shown in Figure 4. Although a filter is incorporated in the equipment for floating the plate batteries, as mentioned above, additional condensers are used at the transmitting station to obtain improved results.

With a minimum of special equipment both plate and filament power are thus provided at the transmitting and receiving stations as well as at the control office. The supply is maintained not only at very constant voltage but with almost entire absence of ripples which could cause noise in the voice-frequency circuits.

The Story of Short-Wave Transoceanic Telephony

By A. A. OSWALD
Radio Research

THE year 1924 brought forth the conclusion that the results of two years of previous work on short waves justified an active interest in the problems of short wave operation on a large scale. Orders to build at Lawrenceville, New Jersey, came in 1928; 1929 sees the station in operation. The development and installation of the United States terminals for the four new transoceanic radio-telephone channels is a splendid example of cooperation in research and engineering. Extending over a half-decade, the project which culminates in the stations at Lawrenceville and Netcong, New Jersey, and their counterparts in England involved the work of several score of engineers, scientists and others. By tracing the history of the work, there may be given a new impression of its magnitude; by mentioning some of the men who contributed, an idea may be conveyed of the variety of talents required for its success.

Until the latest stages of this work brought its problems of systems development, short-wave investigation was confined to groups working at first under H. W. Nichols and after his death under W. Wilson. Late in 1921 R. A. Heising and J. F. Farrington began a study of methods of generating and receiving radio signals with high frequencies and measuring the intensities of their fields. These investigations dealt with comparatively low powers, not exceeding about 200 watts; so successful were they that the design of higher-powered equipment was initiated. J. C. Schelleng and E. B. Ferrell, working on short-wave transmitters, developed power amplifiers, for association with Mr. Heising's high-frequency oscillators, to the point of putting from three to five kilowatts into the transmitting antennas. J. C. Gabriel and G. Thurston, under the direction of Mr. Farrington, further developed the generating and modulating circuits and added crystal control. With the added power field-strength measurements were made on several wavelengths at distances up to a thousand miles in various directions. Meanwhile H. T. Friis and E. Bruce concerned themselves with short-wave reception, and devised suitable antenna systems, receivers, and field-strength measuring equipment.

A further simultaneous survey of field strengths at great distances over a wide area was then made; using the various portable measuring sets that had been developed, men from the Laboratories and the American Telephone and Telegraph Company made observations on signals from Deal at numerous distant posts. Participants in this experiment were: C. R. Englund, F. B. Llewellyn, and F. H. Willis (A. T. & T.), first at Cleveland

Engineers associated with the development of the radio transmitters, on the steps of the main building at Lawrenceville. Left to right: E. B. Ferrell, F. F. Merriam, A. Oxehufwud, N. F. Schlaack, C. F. P. Rose, N. E. Sowers, E. J. Sterba

and later at Chicago; J. G. Chaffee, E. J. Sterba, and S. Wright, first at Minneapolis and later at Dickinson, North Dakota; J. F. Farrington, E. G. Ports, and E. A. Krauth, first at Shelby, Montana, and later at Seattle; C. V. Litton, H. C. Baumann, and G. M. Eberhardt, on a truck moving from fifty to three-hundred miles west of New York; F. R. Lack, G. Thurston, and G. Southworth (A. T. & T.), on the steamship "Republic" bound for Bremen; E. Bruce, F. A. Hubbard, and G. D. Gillett (A. T. & T.), on the steamship "Minnewaska" bound for London; and A. G. Jensen, at New Southgate, England. Between Deal and New Southgate, where Mr. Jensen has been assisted by English engineers, these observations have continued up to the present.

The good results of the tests warranted a commercial trial; in 1927 the Deal transmitter was associated with the New Southgate receiver as an eastbound short-wave experimental channel, auxiliary to the long-wave system which was by that time in full commercial operation. During that summer it could always be used in combination with the long-wave westbound channel, and, indeed, it was in use more than half the time, under the direction of N. F. Schlaack. This operation clearly demonstrated the complementary properties of long-wave and short-wave systems. Of the two major hazards to good radio transmission, static and magnetic "storms", the long-wave system proved adversely affected by the former and comparatively little affected by the latter, whereas the short-wave system showed the reverse properties.

So ended the initial experimental stage of the development, the stage in

which the fundamental circuits were determined. The design of a first commercial transmitter was next undertaken by the late H. R. Knettles, under the supervision of the writer and assisted in the mechanical design by J. L. Mathison. E. J. Sterba and E. B. Ferrell worked at Deal on directive transmitting antennas; Messrs. Friis, Bruce and R. S. Ohl continued at Cliffwood their work on directive receiving antennas and other receiving problems. The first transmitter designed with commercial operation in view was installed at Deal, and at Cliffwood a receiver was built by H. C. Baumann to serve as a model for later commercial design.

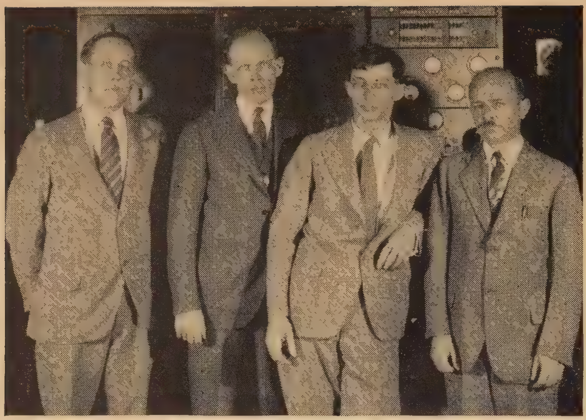
The success of the short-wave development and the increase in transatlantic traffic over the long-wave system combined to decide the American Telephone and Telegraph Company and the British Post Office to establish a complete two-way short-wave channel, to be opened June 1, 1928. To a site purchased at Netcong the Cliffwood receiver was accordingly moved by E. J. Howard and L. R. Lowry, for use in association with the transmitter at deal. Systems groups,* which had designed wire-line equipment for the long-wave channel, installed at Deal, Netcong, and Walker Street the necessary additional equipment, incorporating improvements made in the meantime, and the channel went into service at the time scheduled.

But use of the transatlantic service was increasing so rapidly that the American Telephone and Telegraph Company found that more channels and facilities independent of those at Deal would be necessary to handle the business. Ordering in May, 1928, a channel to replace Deal, and two more to England and one to South America, the American Company purchased in August a transmitting site at Lawrenceville and scheduled the opening of the first transmitter for June 1, 1929. The intensive work necessary to meet this date was immediately started by these Laboratories and the Long Lines Department. Mr. Schelleng continued circuit studies toward further improvement of the transmitters, and Mr. Friis of the receivers; the coordination of the group activities of the Laboratories, and the design and layout of the apparatus and stations, were the responsibility of the writer.

M. E. Fultz, C. F. P. Rose and A. Oxehufwud, assisted by J. L. Mathison, redesigned the transmitter in accordance with experience gained at Deal and incorporated crystal-oscillator systems based on the work of F. R. Lack. N. F. Schlaack and E. B. Ferrell set up and tried out at Deal all doubtful features of the new de-

Engineers associated with the development of short-wave vacuum tubes. Left to right: front, H. A. Pidgeon, V. L. Ronci; back, H. E. Mendenhall, J. O. McNally

*Bell Laboratories Record, *April,* 1926, *page* 44.



Engineers associated with the development of the radio receivers. Left to right: F. A. Hubbard, F. A. Polkinghorn, J. C. Gabriel, J. L. Mathison

the antennas and transmission lines and gave technical supervision to the Long Lines crews which erected and tested them. Work extended to holidays and artificially illuminated nights. Tracings taken in late evening from drafting boards under Mr. Mathison's supervision at West Street were rushed to Lawrenceville to guide the following morning's work.

Meanwhlie F. A. Polkinghorn, with the assistance of F. A. Hubbard, J. C. Gabriel, E. G. Ports, J. L. Mathison and H. L. Holley, supervised the design and construction of a receiver based on a model constructed and tested in the Laboratories. This model incorporated many new features of commercial form but embodied substantially the fundamental circuits previously determined by Mr. Friis and his group

sign. M. E. Fultz and F. F. Merriam, in cooperation with the American Company's architects, prepared the station plans, including the safety system and other operating features. In September the Long Lines Department broke ground at Lawrenceville, and by January the station was sufficiently advanced to permit installation of the power equipment. Technical supervision of its installation and test was given by Messrs. Oxehufwud and Rose, assisted by B. H. Nordstrom, and by T. J. Crowe, experienced as foreman of the Plant Department's electricians. Messrs. Ferrell and Rose, and N. E. Sowers, conducted tests and adjustments on the radio apparatus. Messrs. Sterba and Merriam, assisted by G. M. Eberhardt and P. H. Smith, designed

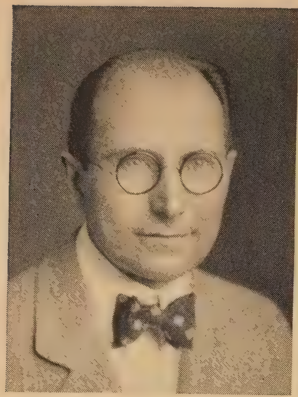
The Laboratories' short-wave receiving laboratory at New Southgate, England, where A. G. Jensen (right) is assisted by R. Hamilton and other British engineers

at Cliffwood. The set, wired at West Street by A. C. Chaiclin and tested there by Messrs. Gabriel and Hubbard with the assistance of A. Hartman and D. M. Black, was finally installed at Netcong by Messrs. Hubbard and Black, who then gave it further tests with the cooperation of the Department of Development and Research. Mr. Bruce, assisted by L. R. Lowry, R. M. Whitmer and F. Giovanini, gave technical supervision to the erection of the receiving antennas by Long Lines crews; tested the antennas; and substituted, for the open-wire transmission lines previously used, the concentric-pipe transmission lines developed by C. B. H. Feldman at Cliffwood.

Engineers associated with the development of the wire-line terminal equipment. Left to right: front, W. F. Malone, C. C. Munro, F. L. Morgan, H. M. Pruden; back, P. V. Koos, H. H. Spencer

At transmitting, receiving, and control stations, the work of the Systems Development Department on voice-frequency equipment was meanwhile being completed. E. D. Johnson, of R. S. Wilbur's group, prepared the circuits for line-terminal audio-operation and testing, with the assistance of E. Vroom, C. C. Munro, and H. M. Pruden; and J. A. Coy, working under D. C. Meyer, made general layouts of the necessary equipment. Detailed engineering of equipment, and its installation, was then undertaken by E. J. Johnson's group. Under J. L. Larew the wire-terminal power plant for Lawrenceville was designed and tested by H. H. Spencer, and for Netcong and Walker Street by R. P. Jutson. All other telephone equipment became the concern of R. H. Kreider, under whom J. E. Cassidy and P. V. Koos designed and installed equipment at Lawrenceville, W. H. Bendernagel and F. L. Morgan at

Engineers in charge of the development of the wire-line terminal equipment. Left to right: front, D. C. Meyer, E. J. Johnson, R. H. Kreider, E. Vroom; back, K. M. Fetzer, J. E. Cassidy, E. D. Johnson, J. L. Larew



J. A. Coy

F. R. Lack

E. Bruce

Netcong, and R. B. Simon, W. F. Malone, J. D. Nedelka, F. A. MacMaster, J. N. Loomis and E. A. Bescherer at Walker Street. This work was complete when E. D. Johnson's group returned to test its circuits in their actual physical embodiment and announced them satisfactory.

Contributions from other groups were too numerous for complete mention. Of special interest are a band-pass filter, to operate at an intermediate radio frequency of about four hundred kilocycles, from C. E. Lane and his men; and a new differential relay from J. R. Fry's group. In the vacuum-tube laboratory directed by M. J. Kelly, special tubes for receiving circuits, including new shield-grid types, were developed by H. A. Pidgeon and J. O. McNally, and new power tubes for the transmitters were developed to meet high-frequency requirements by H. E. Mendenhall, V. L. Ronci and C. E. Fay.

Throughout all the development, moreover, the unfailing support, extending to overtime work, of the Plant and Commercial Departments was indispensible. In a special shop in 4-K, F. Berger took charge of building the transmitting and receiving sets. By arrangement with B. B. Webb's group, maximum assistance in the commercial phases of the work was secured. W. F. Johnson, assisted by H. W. Dippel and R. W. Mutchler, arranged for the purchase and delivery of the necessary materials from suppliers. Under K. B. Doherty, J. F. Lewis handled estimates, case-authorization, ordering and billing; and G. F. Doppel the manifold problems of scheduling and production, with the assistance of C. W. Stevens and H. S. Enger at West Street and P. May at Lawrenceville. C. Deyo took charge of storage and export.

On June 1 as scheduled a year before, the first transmitter at Lawrenceville was cut into operation, and commercial service was initiated by a call from Cleveland to London. A week later the new channel was reported by the Long Lines Department as giving substantially better service than either of its predecessors. The second channel, replacing Deal, will be opened on September 1, and the third on December 1. Service to South America, where E. J. Howard is now making transmission observations on signals from Deal, opens next February.

Commercial Problems in Engineering, Manufacture, and Installation

By B. B. WEBB
Commercial Relations Manager

THE tasks of manufacturing, delivering, installing and testing the telephone equipment developed and designed by these Laboratories are normally undertaken by the Western Electric Company, the manufacturing organization of the Bell System. It is but rarely that our Shop, primarily an adjunct to development rather than a unit for industrial manufacture, is called upon to build extensive equipment for commercial use. It is sometimes so, however, when complete novel systems are projected—such systems as the Rocky Point long-wave transatlantic transmitter and, most recently, the new transoceanic short-wave telephone for Lawrenceville and Netcong, N. J.

The reason for these exceptions to the System's usual manufacturing procedure is simple. So much of novelty is involved in the principles employed and the designs proposed that it is economically advantageous to secure the closest possible contact between the developing engineers and the manufacturing mechanics. And these intimate relations, valuable in any case, are essential when, as with the transoceanic system, the time schedule is contracted to a minimum.

A manufacturing enterprise so large and complex as that for the transoceanic equipment involves many activities other than those in laboratories and shops—and machinery, tangible and intangible, far more various even than that on our fourth floor. To free the engineers and mechanics from all other work than that in which they are specialists, the staff departments undertake these manifold activities, and endeavor to carry them out with minimum distraction and maximum assistance to the engineering and manufacturing personnel. Here again the novelty of the project is operative, offering for solution novel problems of estimating, purpurchasing, scheduling, costing, accounting, shipping, billing, and the like, and commanding the attention of men not only specially trained and experienced in these matters but also technically trained to be appreciative of the scientific and mechanical aspects of the projected system.

Authorizations from the Western Electric Company, based on cost estimates made by the Commercial Relations Department, led to the origination of cases to which to allocate the expense of manufacturing the five transmitters and receivers (four for the Long Lines Department at Lawrenceville and Netcong, and one for the International Standard Electric Company at Buenos Aires), and the vacuum tubes, sleet-melting apparatus, oil filters, and other equipment, and installing* this equipment at Lawrence-

* *The line-terminal equipment and its associated power equipment were installed by the Western Electric Company under the engineering supervision of the Laboratories.*

ville and Netcong. What to manufacture and what to buy elsewhere were decided; orders were immmediately placed outside for apparatus whose production would take considerable time; and pressure was exerted on suppliers, in many cases by visits to their factories, to ensure that materials and equipment would be available when needed. Special storage space in a nearby warehouse gave indexed accommodation to materials, between their receipt and their withdrawal for use.

A schedule was set up with the Shop, calling for the completion of the first transmitter on January 15 and one per month thereafter, and of the first receiver on May 15. Since such a manufacturing load could not be handled in other than a special way, additional space and personnel were acquired: a separate group of twenty-five men, occupying the entirety of Section 4-K, undertook the construction of the sets. Manufacture proceeded smoothly and according to schedule. On the successive completion of the transmitters, they were dismantled, packed bay by bay in specially constructed cases, and shipped by truck to Lawrenceville. To Buenos Aires went, specially packed, a complete consignment of 808 items, weighing 104 tons.

At Lawrenceville other incoming equipment, freighted to Trenton, had to be trucked to Lawrenceville, received, stored and indexed, and certain items purchased from local suppliers during installation also had to be cared for. To afford these and numerous other commercial services, the Commercial Department permanently stationed a representative at Lawrenceville.

Unlike the engineering work on such a project the commercial work involves, sooner or later, every branch of the entire commercial organization. The expense is budgeted. Time cards charging labor to the job are rated from payroll records and pass to accounting organizations where, with orders and stock-withdrawals, they are entered in case sheets and case-cost reports, and included in the bills, the journal and the ledger. Invoices from suppliers are checked to requisitions and receivals, and paid by the vouchering and financial organizations. All transactions are continuously audited. Merchandising groups stock and store, ship and receive; service groups blueprint, type and file.

Morning conferences between the engineers and the commercial men coordinated the many endeavors and ensured that all was proceeding as it should. Pending the completion of the task most of these activities still continue. The cost accounting is being carried out currently, to facilitate prompt final billing of the job to the Laboratories' customers. Not until this billing has been rendered, and credit on its account approved and recorded, will the major commercial concern with the transoceanic shortwave project be completed.